Flood Mitigation Needs Assessment

Six Mile Creek, Salmon Creek, Fall Creek, & Cayuga Inlet
Tompkins County, New York

September 2005

MMI #2343-01

Prepared for:

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1.0 Introduction

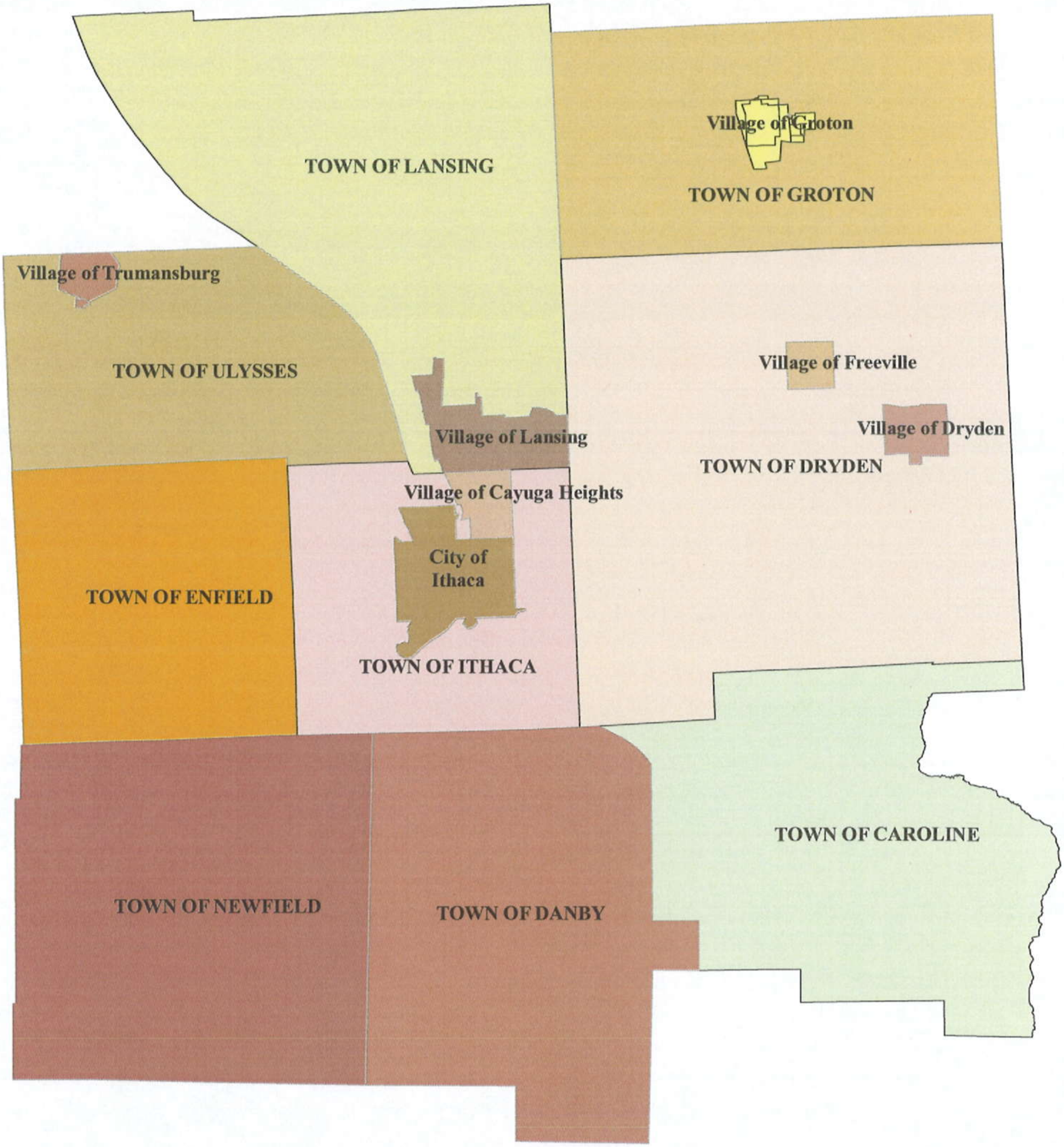
1.1 Background and Purpose

The Tompkins County Planning Department has retained Milone & MacBroom, Inc. (MMI) to conduct a Flood Mitigation Needs Assessment for four watersheds in the county as part of an ongoing planning and mitigation effort. The watersheds evaluated were Six Mile Creek, Salmon Creek, Fall Creek, and Cayuga Inlet.

Tompkins County encompasses the City of Ithaca as well as the Towns of Ithaca, Lansing, Groton, Dryden, Caroline, Danby, Newfield, Enfield, and Ulysses. Figure 1-1 is a location plan of the county.

The Tompkins County Planning Department provides planning and related services to both county government and local municipalities. The Department is charged with preparing a comprehensive development plan; collecting and distributing data and information on population, land use, housing, environment and community facilities; preparing planning studies and analyses; and acting as a resource for other county agencies as well as the member communities seeking outside funding.

In 1997, the Planning Department initiated its *Flood Hazard Mitigation Program,* funded through the county tax base. The program set up a system whereby a total of $25,000 was made available each year for flood hazard mitigation projects within Tompkins County. Funding was contingent upon a one-third county grant, with one-third matching requirements by the project proponent (typically the property owner) and one third match by the municipality in which the project was located. In instances where the municipality and the project proponent were one in the same, their share was two-thirds. In-kind services were eligible to meet all or a portion of the matching requirements, for individuals as well as municipalities.



Engineering, Landscape Architecture and Environmental Science

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Flood Mitigation Needs Assessment

LOCATION: Tompkins County, NY

MMI#: 2343-01
MXD: H:Figure 1-1.mxd
SOURCE: DEP Bulletin No.40

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Location Plan
Tompkins County

DATE: September 2005
SCALE: 1:200,000

SHEET: **Figure 1-1**

In the past, the county solicited *Flood Hazard Mitigation Program* project proposals on an annual basis. Application forms were developed on which project proposals were submitted by interested parties. These proposals were then reviewed and funding awards were made accordingly. The program was administered in coordination with the Tompkins County Soil and Water Conservation District (TCSWCD). During the time that the program was active (1999 through 2001), project awards were typically in the $5,000 range, with total project costs in the $15,000 range.

Coincident with the inception of the *Flood Hazard Mitigation Program,* a five-member Flood Hazard Advisory Committee was established, with representation by County Planning and Engineering, the Tompkins County Environmental Management Council, the Tompkins County Water Resources Council, and the Soil and Water Conservation District. The Advisory Committee last met in late 2001, at which time funding was put on hold pending reorganization and reassessment of the flood hazard mitigation needs within Tompkins County. The intent was, and remains, to restructure the *Flood Hazard Mitigation Program* to address a more holistic watershed approach. This will enable individual projects to be assessed and evaluated based upon their merit and function within the framework of the overall watershed needs.

The following objectives have been identified for the subject planning initiative:

- to evaluate effective flood mitigation in Tompkins County;
- to re-emphasize watershed approaches through the development of a strategy to address watershed needs;
- to consider cumulative flood mitigation measures; and
- to identify watershed management and flood mitigation priorities.

In all, nine watersheds drain into Cayuga Lake within Tompkins County. These watersheds are depicted in Figure 1-2. They are:

- Salmon Creek;
- East Cayuga Lakeshore North Watershed;
- East Cayuga Lakeshore South Watershed;
- Fall Creek Watershed;
- Cascadilla Creek Watershed;
- Six Mile Creek Watershed;
- Cayuga Inlet Watershed;
- West Cayuga Lakeshore South Watershed; and
- Taughannock Watershed

In 2003, a pilot watershed assessment was conducted for Six Mile Creek, the results of which are presented in the subject document. In 2005, watershed assessments were completed in the Salmon Creek, Fall Creek, and Cayuga Inlet watersheds. Funding for the study of the latter three watersheds did not allow analysis to the same extent as the Six Mile Creek.

1.2 Project Stakeholders

Numerous stakeholders have been identified for the Flood Mitigation Needs Study, including the individuals and organizations summarized in Table 1-1.

TABLE 1-1
Partial List of Project Stakeholders

Organization	*Principal Contact*
Tompkins County Planning Department	Kate Hackett
Tompkins County Engineering Department	John Lampman, Sr. Civil Engineer
Tompkins County Soil & Water Conservation District	Craig Schutt, District Manager
Town of Caroline Watersheds Committee	Todd Schmit, Chair
Town of Ithaca Planning Department	Sue Ritter
U.S. Geological Survey	Todd Miller
City of Ithaca Drinking Water Treatment Plant	Roxy Jonston
City of Ithaca Public Works Department	Larry Fabbroni, Assistant Supt.
Town of Dryden Conservation Advisory Council	Dan Karig
Cayuga Lake Watershed Network	Sharon Anderson

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Flood Mitigation Needs Assessment

LOCATION: Tompkins County, NY

MMI#: 2343-01
MXD: H:Figure 1-2.mxd
SOURCE: DEP Bulletin No.40

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Cayuga Lake Watersheds Location Map

DATE: September 2005
SCALE: 1:200,000

SHEET: Figure 1-2

2.0 *Existing Geomorphic Conditions in Tompkins County*

2.1 *Geologic and Geomorphic Background*

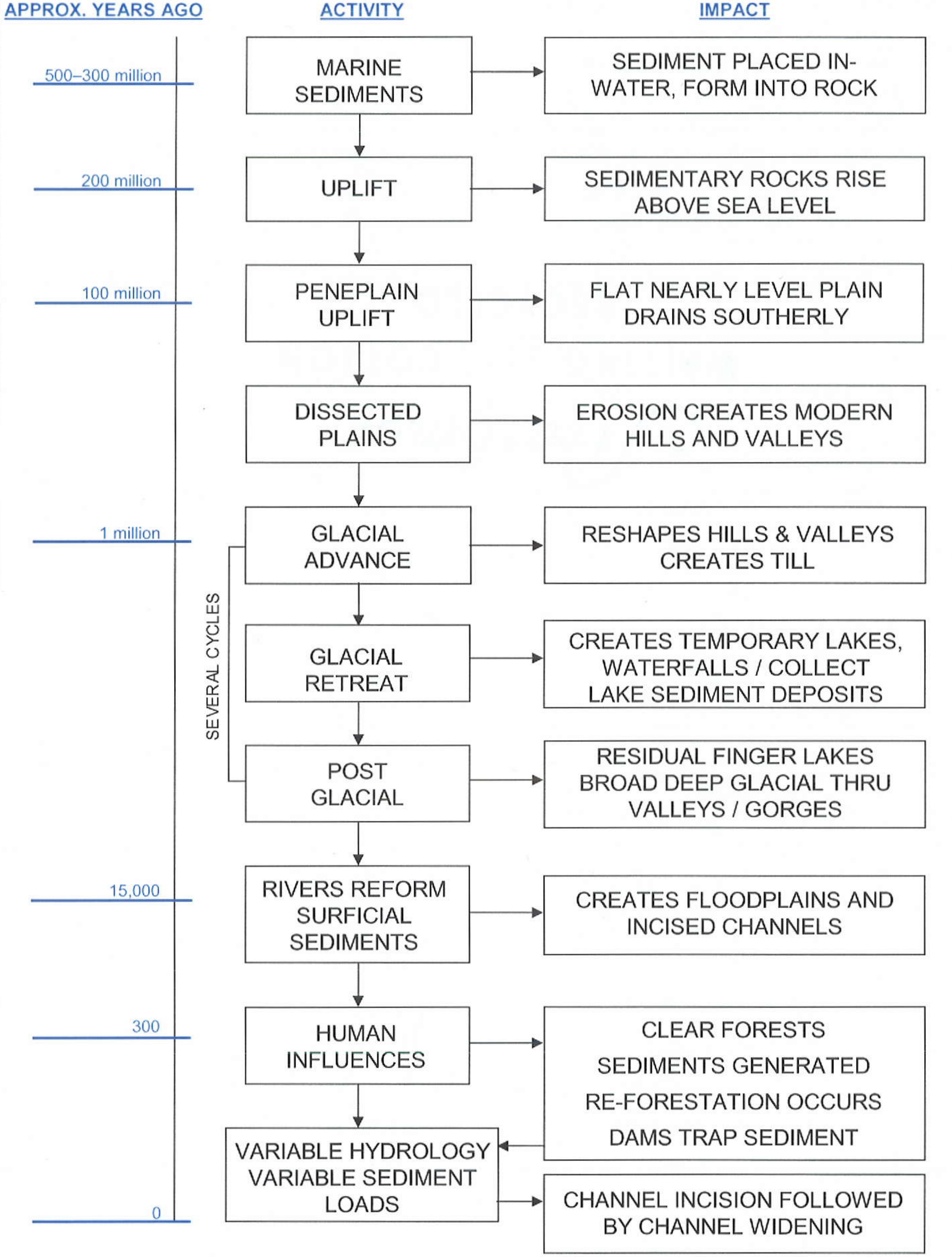
The Finger Lakes region of New York is often cited for its classic examples of "U-shaped" valleys carved by the advancing glaciers of the most recent ice ages. Indeed, these valleys are the prominent characteristic of the area, but many geologic forces have shaped the landscape of Tompkins County, and these must be addressed to understand the natural processes in the Six Mile Creek basin. Figure 2-1 presents a summary of regional channel evolution.

Most of the consolidated sedimentary rocks in the Ithaca area were formed 375 million years ago during the Devonian period. At least 1.2 miles (vertical) of sedimentary rock have been removed from the Ithaca region by erosion over several million years, including erosion that occurred over several glacial periods.

The cycle between glacial periods is estimated at 100,000 years to 150,000 years (Bloom, 1990). The most recent glaciers (known as the Wisconsin advance) were completely retreated from New York about 11,000 years ago. Between 13,500 years ago and 11,000 years ago, while the glaciers were melting, several ancient lakes existed in the Ithaca region, each with different elevations and outlets. Each ancient lake is associated with ancient beaches, ancient deltas, outlet stream deposits, and lake-bottom deposits that currently exist as landforms and subsurface deposits.

SUMMARY OF REGIONAL CHANNEL EVOLUTION

FIGURE 2-1



As ancient lake levels formed and were replaced by lower lake levels, ancient deltas formed at different elevations in stream valleys. The net result is a series of ancient deltas that lie along the valley main stems, found along several of the major streams draining toward Cayuga Lake. Existing streams have eroded and cut into some of the ancient deltas that were deposited by their ancestral streams, with the result being the downstream transport of sediment.

Some of the boundaries of the ancient lakes can be approximately located based on the locations on landforms. For example, an ancient beach deposit marks the uppermost elevation of Lake Ithaca (1,020 feet) far to the east of the Cornell University campus. An ancient delta located beyond the eastern edge of the Cornell University campus (elevation 970 to 975 feet) marks another position of ancient Lake Ithaca. Southwest of Ithaca, three small ancient deltas lie along Coy Glen, at elevations of 980 feet, 1,040 feet, and 1,060 feet.

Many are familiar with the classic profile of rivers and streams, beginning in high-gradient areas with many riffles, flowing through intermediate areas with pools and riffles, and eventually flowing through large, low-gradient floodplain areas that may be characterized by meanders and wide channels. Although these types of streams are found in the northeastern United States, most rivers in the Ithaca area are not in equilibrium with their landscape due to the glacial cycles.

Fall Creek, flowing through the largest contributing watershed in Tompkins County, is a good example of a stream that is not in equilibrium due to recent glacial forces. The midstream reaches of Fall Creek have a base level control due to the presence of bedrock at "flat rock." Upstream of flat rock, Fall Creek has inherited large meanders that were formed under previous flow conditions. The downstream reaches of Fall Creek (in the vicinity of the Cornell University campus) is characterized by deep gorges with near-vertical walls.

Fall Creek is an example of a river that can not easily adjust to its down-valley slope. Because the regional base level control (Cayuga Lake) is so much lower in elevation than the upper portions of the watershed, and because the Cayuga Lake valley is U-shaped, Fall Creek must fall through a very large change in elevation in a relatively short distance. Fall Creek has naturally worked toward cutting a more gradual profile, resulting in gorges in the downstream reaches, while constrained by other bedrock base level control at flat rock.

The elevation change in the Ithaca portion of the Six Mile Creek drainage basin is less drastic than the Ithaca portion of Fall Creek. As a result, Six Mile Creek is more aligned with its down-valley slope than is Fall Creek. However, Six Mile Creek does have evidence of non-equilibrium, such as the lack of a wide floodplain in its lower reaches and the presence of a wide floodplain closer to its headwaters. This is the result of the natural geology of the watershed and is atypical for the rest of the United States.

Because rivers in the Ithaca region are not in equilibrium with the current landscape due to glacial processes, they are actively eroding many of the sediments that were deposited directly by glaciers and their melt water, or that formed beneath the ancient lakes, at the edges of the ancient lakes (the ancient deltas), or during outflow from the ancient lakes. This is a natural process that has occurred in many other watersheds that have already reached equilibrium conditions. In the watersheds under study, this process is ongoing. In geomorphic terms, the term for erosion over an expansive area is "denudation." Rates of denudation typically indicate a vertical loss of material averaged over a wide area.

Denudation rates for glaciated areas have been estimated at 3.0 centimeters (cm) per thousand years, and there is evidence that the Ithaca region has lost an average of 4.5 meters (vertical) since the beginning of the last glacial cycle (Bloom, 1990). Denudation rates are higher for intense agricultural areas, such as the Mississippi valley (estimate of

5.0 cm per thousand years), and for mountainous areas (as much as 13.0 cm per thousand years in the Sierra Nevada). Nonetheless, the estimate for glaciated areas indicates that the Ithaca region may continue to experience erosion and downstream sedimentation at an overall vertical rate of 3.0 cm per thousand years, at a minimum.

If left alone, these streams will continue in their dynamic nature towards eventual equilibrium in the environment. The challenge, however, is the integration of this natural process with existing development and the management of natural resources. An example of this is management challenge is the ongoing sediment deposition in the City's and Cornell University's sources of drinking water supply.

2.2 Channel Incision

The dominant fluvial process along much of the Finger Lakes Region is the incision of channels into the landscape. The overall process of regional landscape degradation has been described by Von Engeln (1961) and is summarized in section 2.1 of this report. Schumm, et. al. (1984) have described several different types of channel incision, all of which have been observed in the watersheds under study.

- *Rills* – are small intermittent channels as a result of erosion by overland flow. They are often seasonal and are "plowed" out during planting.

- *Valley Side Gullies* – are small to intermediate size channels, generally with relatively high steep unvegetated banks, extending down the side of steep valley walls without a defined valley or watershed.

- *Valley Bottom Gullies* – are found where intermittent or perennial flows have eroded a new steep sided channel across a valley base or floodplain to the valleys main stream. As a result of their position in the valley bottom, they often erode deeper to match the grade of an entrenched river or extend longer to reach a meandering river into which they discharge.

- *Entrenched Streams* – occur where a natural stream has become incised in its own valley and below the elevation of its floodplain. Entrenched channels may occur in bedrock or in surficial soils, or in earlier sediment deposits.

Channel degradation can have mild to significant adverse impacts to both natural and cultural systems. Much depends upon the rate and magnitude of degradation and whether systems can adjust to the degradation. For example, rapid degradation can undermine bridge foundations or pipe crossings in less than the physical life span of the structure and require remedial action. Sediments transported downstream from incised channels can settle in and fill reservoirs prior to the life span of the dam.

Incised channels have significant ecological impacts. The deep channels have increased flow capacity and thus have less frequent floodplain inundation. This reduces over-bank floodwater storage, leading to higher peak flows and less sediment deposition on the floodplains. Alluvial ground water levels, dependent on river stages, will decline. This tends to "dry up" or eliminate riparian wetlands. Table 2-1 lists some of the adverse impacts of channel incision.

TABLE 2-1
Adverse Impacts Due to Channel Incision

Natural	***Anthropogenic***
creates excess sediment	undermines bridges
banks erode, trees collapse	exposes utility pipes
lowers alluvial groundwater levels	reservoir sedimentation
creates unstable bed habitat	loss of riverbank land
reduces biological diversity	downstream flood damages
higher velocities occur	poor channel access
reduces floodwater storage	degrades water quality
increased peak flood flows	
knick points inhibit fish passage	
sediments fill downstream lakes	

3.0 *Concepts in Watershed Assessment and Management*

3.1 ***Principles of Watershed Management***

Many factors require that river management efforts extend far beyond the banks that contain flowing water. Some management issues result from upstream land use, runoff, and sources of pollution. Others arise because of floodplain encroachments, inadequate riparian buffers, or loss of wetlands. The evolving methods of river management emphasize a holistic approach, addressing the watershed and stream corridor in addition to the actual channel. Traditional approaches to river management are often limited in scope, prohibitively expensive, and environmentally unsound. The concept of managing the watershed and corridor as well as the river channel itself provides an alternate approach that allows each river function to be managed at the appropriate level.

Watershed management has evolved in response to the need for a broad approach that considers rivers to be important natural resources with many, often competing uses. It is essential to recognize that, besides conveying storm runoff, streams serve many other ecological, economic and social functions, and the planning and design of management systems must consider water supply needs, recreational uses, wildlife, aesthetics, and the cost and maintenance of the management measures that are implemented.

The concept of watershed management has been in existence for many years. The practical application of the watershed management approach is constantly evolving as new technologies are developed. An effective watershed management program should be based on scientific and engineering guidance, but also needs to be communicated to and implemented by the stakeholders of the watershed in a complementary and coordinated effort.

Effective watershed protection involves a multi-faceted approach that encompasses land use (past, present, and future); stream and wetland buffers; responsible development through adequate site selection, design, and maintenance; stormwater best management practices; control of non-stormwater discharges; control of destructive and unnatural erosion and sedimentation; and watershed stewardship programs that have the ability to span corporate boundaries and governmental divides.

The process of watershed management begins with a watershed needs assessment, wherein the following basic tasks are conducted:

- identification of the study area;
- identification and notification of interested individuals, organizations, and public agencies;
- establishment of an advisory or coordinating board;
- collection of existing data and evaluation of existing natural and cultural features;
- collection of new data as needed;
- identification of watershed and stream issues and problems;
- identification of highest priority issues;
- evaluation of alternative solutions to problems;
- researching of funding sources and needed regulatory programs;
- development of a final strategy;
- adoption of a management plan; and finally
- implementation of the plan.

This flood hazard mitigation needs assessment is designed to follow the above approach. The subject document is organized accordingly.

3.2 Stream Dynamics

The movement of sediments through a river system is a complex process, often made up of many cycles of scour, movement, transport and deposition. Sediment movement occurs when water flow exerts sufficient force to overcome the resistance produced by the weight of individual particles, their cohesion to similar particles, and their friction with the streambed. Most sediment is transported during periods of high water flows and high velocities. High flow velocities are able to erode and transport larger particles and so accelerate erosion. Similarly, long-duration floods can cause more erosion and sediment transport as compared to short-duration floods. The sediment concentrations in river water and long-term sediment loads depend on the availability of erodible soil and the ability of a river to transport it.

Aggradation is the general increase in elevation of a long reach of a riverbed over a long period. This process occurs when sediment is continually added to the riverbed, or even the floodplain, and the river does not have the necessary slope, velocity or flow rate to wash away the sediment. Therefore, the riverbed will rise, increasing the slope in relation to the segment farther downstream. This increased slope accelerates erosion, until sediment transport is equal to the sediment supply rate and equilibrium is achieved.

In contrast, degradation is the general lowering of the streambed. This occurs where the slope, discharge and flow velocity combine to transport more sediment than is supplied to a river section. As a result, the riverbed will erode until the slope and velocity are reduced to a point of equilibrium. Natural degradation can result from an uplift of the land, climatic changes, or even an increase in vegetation. Humans can cause or accelerate degradation through watershed development that increases surface runoff and flow rates. Dams on alluvial rivers (i.e. those that are dynamic, whose beds and banks can erode and change course over time) encourage degradation by trapping sediment that would normally be carried downstream.

An entrenched channel is one that has degraded so much that its flood flow is unable to spread across its floodplain. Such channels are confined by well-defined banks that are higher than the mean annual flood level, thereby preventing inundation. Entrenched meanders occur when the channel's original pattern was preserved as the channel degraded, such as in the Grand Canyon. In other words, entrenched meanders are those that have eroded vertically but not laterally. They have steep valley walls on both sides of the meander bends.

Incised meanders occur where the channel has eroded both vertically and laterally. They move downstream by eroding the outside of the bends. They are characterized by steep valley walls on the outside of bends, with mild sloping walls on the inside. Active meandering channels often occur where the river flows through highly erodible sediments, common where glacial lakes occupied the land.

3.3 Sediment Budget and Transport Mechanisms

Open channels with flowing water have a discrete ability to transport sediment based upon their flow velocities, shear strength, flow rates, and flow duration. The first two parameters are related to channel slope, friction, width, and water depth. Steep and smooth channels can carry more sediment as compared to low gradient or rough high friction channels.

Under equilibrium conditions, the sediment load produced by a watershed is equal to the channel's sediment transport capacity. Rivers that can transport more sediment than that which is supplied to them will tend to scour any erodible bed or bank material, while rivers with a transport capacity that is lower than the watershed yield will tend to aggrade or deposit sediment on the bed or floodplain. The basic relationship is:

$$\Delta S = \Sigma Q_s - Y$$

where:
ΔS = change in channel sediment storage;
Q_s = channels sediment transport capacity; and
Y = watershed sediment yield.

Channel erosion in steep gradient rivers has a vicious, self-perpetuating cycle. As shown by Schemms (1984) model, first they erode the bed where the greatest shear stress exists, concentrating even more flood water in the channel. Then they incise vertically until either the bed slope (and velocity) is reduced, or until the even higher banks collapse, (supplying fresh sediment). Eventually, (after decades or centuries) they reach a new equilibrium. In mountainous and shallow bedrock regions, including Six Mile Creek, incision may cease when bedrock is reached or the riverbed becomes armored with natural rock fragments of cobbles or gravel.

3.4 *Types of Erosion*

Two types of erosion and sediment load can occur in a stream system. The first is called surface erosion and occurs in the contributing watershed to a stream. Surface erosion can occur at construction sites, where bare earth is exposed to the forces of stormwater. It can also notably occur as a result of agricultural practices. Sediment load can also be introduced to a river or stream through the application of road sand or through urbanization. The second type of erosion is bed or bank erosion, where the source of sediment is the stream bed or bank walls. While the latter form can be driven by land uses within the watershed, it cannot be controlled through best management practices applied to construction sites, road sanding practices, and the like.

In recent years, local planning and zoning ordinances, as well as state legislation, have focused on erosion control practices for land development, often accomplished through the use of hay bales, silt fences, and sediment basins. Non-point pollution controls have also been the focus of much attention in recent years, with stormwater management treatment and best management practices becoming commonplace.

Hills and uplands form as the result of tectonic forces that warp the earth's crust. Plutonic rock masses can also push up through the crust, forming mountain ranges such as the Sierra Nevada. These mountainous areas and uplands in turn are subject to degradation and wear by the twin processes of surficial erosion and mass movement. Man-made slopes are subject to the same degradation processes. In order to control or prevent this wearing or wasting away of the earth's surface, it is first necessary to understand these two processes of degradation and the factors that affect them (Gray & Sotir, 1996).

Surficial erosion is the detachment and transport of the surface layers of soil by wind, water, and ice. Common forms of surficial erosion include rainfall and wind erosion. This type of erosion is most notable at poorly managed construction sites on exposed steep slopes. However, erosion can also occur along stream banks, where high velocities erode vulnerable, particularly unvegetated, banks.

Mass movement involves the sliding, toppling, falling, or spreading of fairly large and sometimes relatively intact masses. A slide is a relatively slow slope movement in which a shear failure occurs along a specific surface or combination of surfaces in the failure mass (Gray & Sotir, 1996).

Eroding banks can contribute large volumes of sediment to downstream receiving waters. When the receiving waters are of critical value, it is important to minimize the transport of sediment to them in order to maintain water quality. This often entails using bioengineering techniques to regrade and replant the channel banks.

Stream banks may erode and/or collapse due to many different causes and may undergo various types of failures. The potential factors involved in bank failure include watershed hydrology, river flow hydraulics, sediment transport, geology, soils, groundwater hydrology, and vegetation cover. The specific factors in any particular case depend on the type of failure that is occurring.

Surface erosion along stream banks can result in soil loss and bank undercutting. That situation can result in an eventual mass failure, in which the soil slumps or slides as a unit. While bank protection can address the underlying cause of the problem (i.e. surface erosion), the potential for mass failure also needs to be addressed on a location-specific basis. In general, bank failure can be attributed to mass failure or surface erosion.

Numerous types of mass soil failures can occur on steep slopes as summarized in Table 3-1 below.

TABLE 3-1
Types of Mass Soil Failures

Shallow Soil Slides	Occurs on steep low cohesion soils, often-coarse grain material. Has thin slide layers parallel to the surface.
Circular Plane Failures	Deep seated circular failure planes, common on strongly cohesive soils.
Slab or Wedge Failures	Occur on steep moderately cohesive soils. The slabs crack along the top and tip outward with near vertical upper slopes.
Cantilever Failures	Due to the collapse of an undercut block of soil, often due to erosion at the base of the slope.
Granular Flow	An avalanche type failure of dry cohesionless soils on steep slopes, creating a loose layer of debris in a fan pattern.
Saturated Flow	Saturated soils loose their strength and become plastic, often follows heavy rain or high water levels.
Seepage Failure	Caused by saturation of the lower slope, creating a "semi-moon" shaped popout cavity in the lower bank.

The analysis of mass bank failures is a geotechnical evaluation that compares the weight of the soil mass (usually saturated) versus the shear strength of the potential failure plane. Quantitative assessment shows that the higher and steeper banks are more failure prone and that failures decrease as the slope is reduced by past failures building up a berm of debris at the base of the bank. A stable bank may have gradual erosion of individual particles over a long period of time, while an unstable bank is one with frequent mass block failures every few years.

3.5 *Bank Stabilization*

Many methods of stabilizing riverbanks can be employed, each with their own advantages and disadvantages. Milone & MacBroom, Inc. has classified available methods into categories based upon two primary functions, mass failure protection and surface soil erosion protection. A single project site may often use multiple stabilization methods depending on site, soil and slope conditions. In addition, the type of treatment may vary based on its position on the slope and frequency or duration of inundation.

Two types of strategies can be applied to protect a bank undergoing surface erosion from a river. One is in-stream modification of the river's flow patterns to decrease the attack on the bank, and the other is modification of the bank itself to strengthen its ability to resist the erosive forces. In cases where the velocities of the water, rather than the alignment of the river, are causing erosion, modification of the bank is appropriate.

The approach to bank stabilization can be "soft" or "hard." The softest approach relies primarily on vegetation for bank strengthening. This type of approach typically provides instream and riparian habitat value that is superior to the harder methods; however it may not provide the level of stability required to decrease the erosion to acceptable levels. The harder approach relies primarily on structural methods, such as large riprap or concrete, to armor the riverbank. A balance of both soft and hard methods is often required, where some hard structural components are used and combined with softer habitat features to create a stable and attractive bank that provides both instream and riparian habitat.

Included herein as Attachment A is the paper entitled *Merging River Mechanics and Fluvial Morphology for River Management* by James G. MacBroom, P.E. This paper explores how classical hydraulic engineering and fluvial morphology complement one another.

3.6 *Management Practices*

Milone & MacBroom, Inc. team members inspected and reviewed various watershed management practices that have been applied, or could be applied, to minimize flooding, erosion, and sediment problems in the subject watersheds. The specific interest was to identify the performance of individual practices with regard to short- and long-term objectives.

Watershed management measures can be classified by primary functional groups as listed in Table 3-2. Typical measures are tabulated below by primary function.

TABLE 3-2
Primary Watershed Management Functional Groups

Hydrology	*Hydraulics*	*Surface Erosion Control*
detention basins	channel clearing	vegetation ground cover
infiltration systems	channel enlargement	rill/gully controls
created wetlands	bridge improvements	mulch
flood control dams	channel alignment	bio-fabrics
low impact development	floodways	silt fence barriers
Channel Stabilization	*Sediment Control*	*Water Quality*
vegetation	upland sediment basins	catch basins sumps
bio-technical	in-stream silt basins	hooded outlets
stone riprap	vegetative buffers	vegetated buffers
log revetments	diversions	oil traps
geomorphic design	bio-filters	grit chambers
retaining walls		

Hydrologic measures are intended to reduce the volume or peak rate of runoff and ideally attempt to mimic natural conditions. Hydraulic measures are traditionally used to lower flood water levels, reduce flood damages to natural or community assets, or modify flow velocities. Surface erosion controls are used to limit upland erosion on the ground surface to reduce production of sediment, such as at construction sites and agricultural fields. Many types of channel stabilization are in use throughout the country, ranging from simple use of vegetation and stone to geomorphic design process to reshape channels.

In some cases, a reactive strategy is implemented to control sediments that have already been eroded from the earth. In these instances, suspended sediment is captured downstream of its source and is subsequently settled by gravity or is treated through other physical or mechanical mechanisms.

Channels located in alluvial soils that were placed as fluvial sediments have the ability to modify and form their channel widths, depths, and slope in proportion to their dominant discharge. Channels that are initially undersized will be subject to scour that increases their widths and depths in proportion to a channel forming flow rate, while channels that are excessively large will tend to be subject to sediment deposition that decreases width and depth. Over long time periods, alluvial channels thus approach an equilibrium condition.

There has been some discussion in Tompkins County related to use of the hydraulic geometry method of channel analysis for application in developing restoration plans for distressed stream sections.

This concept is the basis of the "natural" design approach to evaluating self-stable alluvial channels. It originated over 100 years ago in India and Pakistan and evolved in the United States beginning in the 1950s, becoming a popular alternative to earlier rigid boundary hydraulic engineering procedures and being much simpler than modern sediment transport techniques. It is only valid for channels at near equilibrium conditions in alluvial material.

Hydraulic geometry relations may be applied by either copying the dimensions of a stable cross section of a similar channel classification, or by using statistical analysis of regional channels to find their bankfull width and depth as a function of the watershed area or preferably their dominant discharge.

There are many alternative techniques available to address channel incision and minimize its adverse impacts. The specific management techniques and design details for individual sites is beyond the scope of this study. However, the broad alternatives that are available are described below:

Do Nothing – This no action alternative allows the renewed channel degradation to continue towards a natural self-imposed equilibrium. The long process (on the order of ten to 100 years) has several consequences, including downstream sediment loading, bank collapses, channel widening and land loss, and ground water recession. In rural areas, this is often acceptable and unavoidable.

Channel Linings – A traditional technique for minimizing channel incision is the use of continuous linings on the bed and/or banks to stop erosion. Common linings include use of concrete, stone riprap, stone filled gabions, precast concrete blocks, and revetments, as well as bio-mechanical plantings such as root wads, fascines, brush layers, and use of dormant cuttings or stakes. Channel linings usually have significant ecologic and hydrologic impacts due to vegetation removal to regrade the bank, loss of habitat diversity, and aesthetics.

Watershed Scale Measures – These are applied in selective situations where broad cultural land use activities are contributing to channel incision. Activities that stimulate incision could include deforestation, over-grazing by cattle, goats or sheep, gravel mining or mineral extraction, channelization, wetland destruction or urbanization. MMI did not observe significant watershed scale activities that would accelerate natural channel incision. Previous activity, such as deforestation, may have contributed to present incisement.

Flow Control – In watersheds subject to deforestation or urbanization, control of peak flood flows is essential to minimize downstream impacts. Higher or more frequent peak flows increase flow velocities and sediment transport that lead to channel bed or bank scour. Specific control techniques include dry storage dams, detention basins, and created wetlands.

Channel Slope Control – Incision can be minimized or contained by use of grade controls or drop structures. Various types of grade controls can be used, including low weirs, flush sills, boulder clusters, anchored logs, gabions, check dams, and rock ramps. It is important to recognize that some grade control structures on perennial streams obstruct fish passage. Site inspections along numerous streams in the subject watersheds revealed that clusters of glacier erratics (boulders of non-native rock) were very effective in stopping knick points.

Velocity Control – Providing increased channel roughness with boulders and anchored logs or bank vegetation reduces flow velocity and subsequent bed erosion. However, extensive roughness may increase flood water levels and the frequency of overbank flows. This is in conflict with many regulatory programs.

Floodplain Connectivity – A fundamental problem with incised channels is that their increasing depth and flow capacity reduces the frequency and magnitude of overbank flow on their floodplains. As they erode and deepen, more and more of the flood flow is trapped in the channel, increasing velocity and shear stress that creates even more erosion. A very effective approach is to mimic a natural system by recreating a new floodplain at a lower grade to increase its usage and reduce velocities via a larger cross sectional area. These compound channels (low flow channel plus floodway) are complex to design, but are very effective if sufficient land is available.

Channel Fill – Occasional suggestions in the literature refer to refilling incised channels to raise the bed elevation and allow floodplain flow again. However, in developed areas, this increases flood levels as well as hazards and is a regulated activity with significant ecological impact. MMI discourages this alternative.

Sediment Load – Channels become incised when sediment transport capacity exceeds their supply of sediment. The Colorado River is a classic example where construction of large dams that trap sediment reduce downstream loads, leading to severe channel incision. Some European rivers are managed by increasing sediment loads to create an equilibrium condition. This is not desirable in many areas due to water supply intakes, water quality, and ecological concerns. Examples of measures to increase sediment loads include removing abandoned dams that remove trees and woody debris and ceasing gravel mining in rivers.

Bank Protection – Armoring the banks with retaining walls helps to protect private property by reducing channel widening. However, it does not address the source of the problem and can accelerate further incision that would undermine the walls as knick points migrate upstream. Similarly, the use of conventional plantings or bio-technical methods to reduce bank erosion is most effective if the channel width is already adequate for flood flows and the banks are regraded below the angle of repose.

It is noted that channel clearing operations that remove trees and debris for local flood protection tend to increase flow velocities and increase erosion by reducing channel roughness. Similarly, channel straightening will shorten the river's length and increase velocity and scour, contributing to more channel erosion.

4.0 *Existing Conditions – Six Mile Creek*

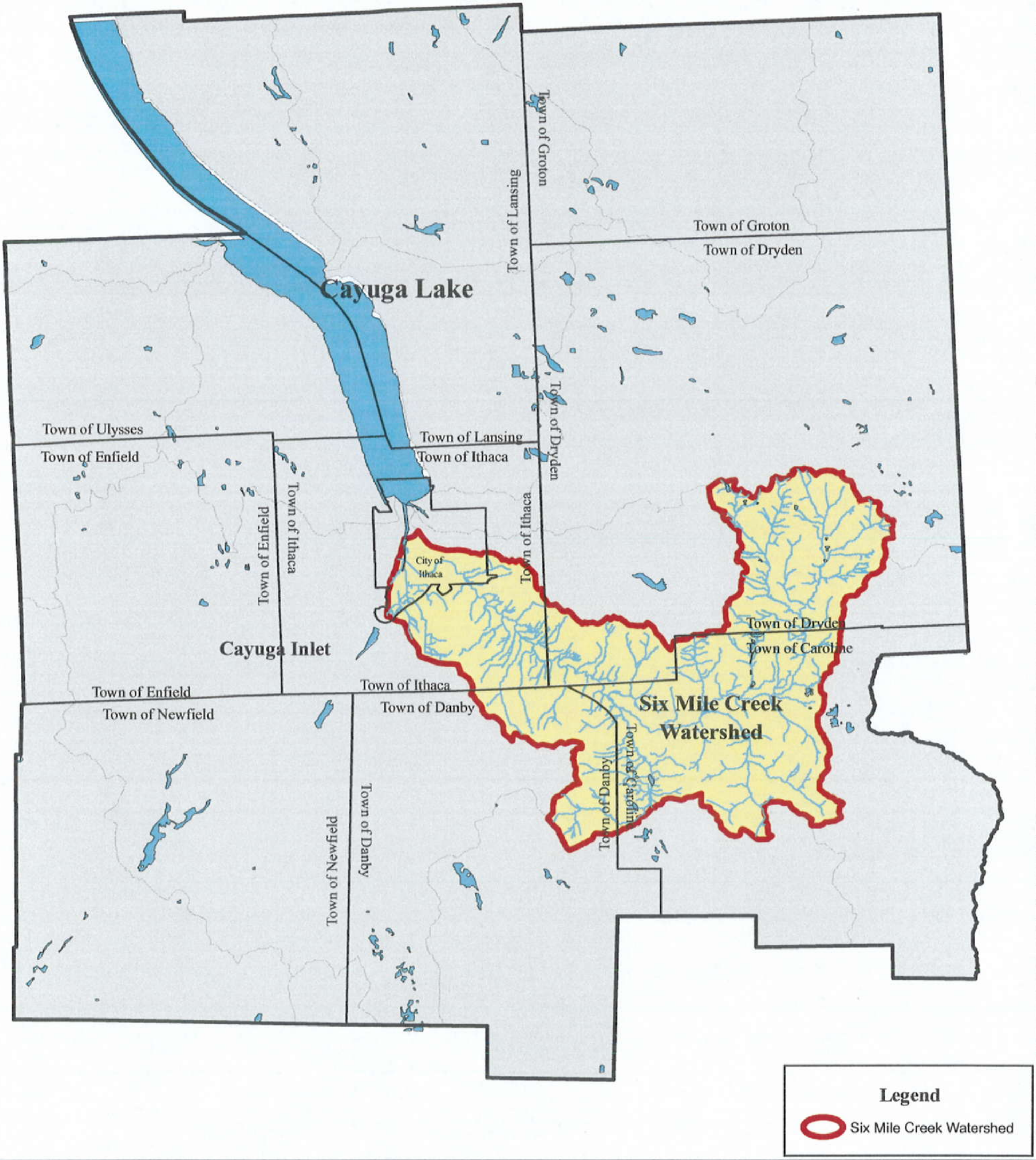
4.1 ***Background***

Before the arrival of the Europeans, the Six Mile Creek valley served as a transportation route to and from Ithaca. An important travelway crossed the creek at Brooktondale, six miles from Cayuga Lake, serving as a landmark to travelers and giving the creek its name (Reidenbach, et. al., 1996).

Figure 4-1 is a location map of the Six Mile Creek watershed. The creek flows through the Towns of Dryden, Caroline, and Ithaca, and finally through the City of Ithaca into Cayuga Lake via the Cayuga Inlet. The contributing watershed to Six Mile Creek is approximately 52 square miles, portions of which lie within the Towns of Caroline, Dryden, Danby, and Ithaca, as well as the City of Ithaca.

The headwaters of Six Mile Creek are located in the Town of Dryden near the intersection of Irish Settlement Road and Card Road. The headwaters of the creek are nestled between Yellow Barn State Forest to the northwest and Hammond Hill State Forest to the southeast. The creek flows in a southerly direction and crosses beneath Irish Settlement Road before flowing into the Town of Caroline.

Six Mile Creek flows parallel to Six Hundred Road in northern Caroline and then crosses beneath Route 79 and Buffalo Road in Slaterville Springs. It turns to the west and flows beneath Creamery Road, Boiceville Road, and then parallels Valley Road behind the Caroline Elementary School into Brooktondale. At Brooktondale, Six Mile Creek turns in a northwesterly direction and runs parallel to Brooktondale Road and Route 79. It crosses beneath Middaugh Road and Banks Road within the Town of Caroline and then skirts the southwest corner of Dryden near German Cross Road before flowing into the Town of Ithaca.



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99 Realty Drive **Cheshire, Connecticut 06410** **(203) 271-1773 Fax: (203) 272-9733** **www.miloneandmacbroom.com**	**MMI#:** 2343-01 **MXD:** H:Figure 4-1.mxd **SOURCE:** DEP Bulletin No.40 — N **Six Mile Creek Watershed Study Location Map**	**DATE:** September 2003 **SCALE:** 1:200,000	**SHEET:** **Figure 4-1**

Downstream (and northwest) of German Cross Road, Six Mile Creek flows into an impoundment known as the siltation dam, constructed circa 1930. This impoundment is located just upstream of the City of Ithaca's drinking water supply reservoir, located in the Town of Ithaca. The siltation dam was installed in an effort to capture suspended sediment upstream of the drinking water supply. The area is actively managed for sediment control, and stockpiles of previously dredged material have been placed adjacent to the impoundment.

The periodic surveys and dredging of the reservoirs and siltation pond provide an unusually good record of sediment loads in Six Mile Creek. The Ithaca Reservoir constructed in the early 1900s, has been dredged to maintain its volume for water supply storage. The upstream siltation basin, constructed circa 1930, has also been dredged.

The estimated average annual rate of sediment accumulation in the reservoir from 1910 to 1925 was 14,000 cubic yards per year, while the sediment dredged from the siltation basin was at an average annual equivalent rate of 15,100 cubic yards from 1963 to 1976. (Roberts, 1978, in the Six Mile Creek Watershed Study). These sediment estimates exclude the wash load that remains in suspension and passes through the impoundments to Cayuga Lake.

Downstream of the siltation dam, Six Mile Creek crosses beneath Burns Road, located within the Town of Ithaca and then it flows into Ithaca Reservoir, where ±5.5 million gallons of water is withdrawn each day to supply drinking water to the residents and businesses within the City of Ithaca as well as portions of the Town of Ithaca. Cornell University, portions of which are located within the City limits and the limits of the Town of Ithaca, is supplied by its own system.

Ithaca Reservoir has been a water supply source since 1892, when the Ithaca Light & Power Company purchased the mill and dam at the Van Natta's Dam complex. In 1902, the utility constructed an upstream 30-foot high dam and laid a 24-inch aqueduct along the creek. Shortly thereafter, they built a water filtration plant. In 1904, the City of Ithaca purchased the dam and filtration plant, and by 1911, construction of a 60-foot dam was completed upstream of the initial dam. The reservoir continues to provide potable water to the City and portions of the Town of Ithaca.

The overflow from the 60-foot reservoir dam is directed downstream, where it is impounded by the 30-foot high dam. The surrounding area is known as the Wildflower Preserve and is heavily utilized by hikers, walkers, and joggers. The creek flows through a largely bedrock channel downstream of the lower reservoir and then onto Van Natta's Dam within the City of Ithaca.

Downstream of the impoundments, Six Mile Creek flows into Cayuga Inlet. The inlet is approximately one mile in length and is located between the mouth of Six Mile Creek and Cayuga Lake. The creek is channelized in the downstream reaches, beginning at the Aurora Street bridge.

Table 4-1 presents a listing of subwatersheds within Six Mile Creek. These are shown graphically in Figure 4-2.

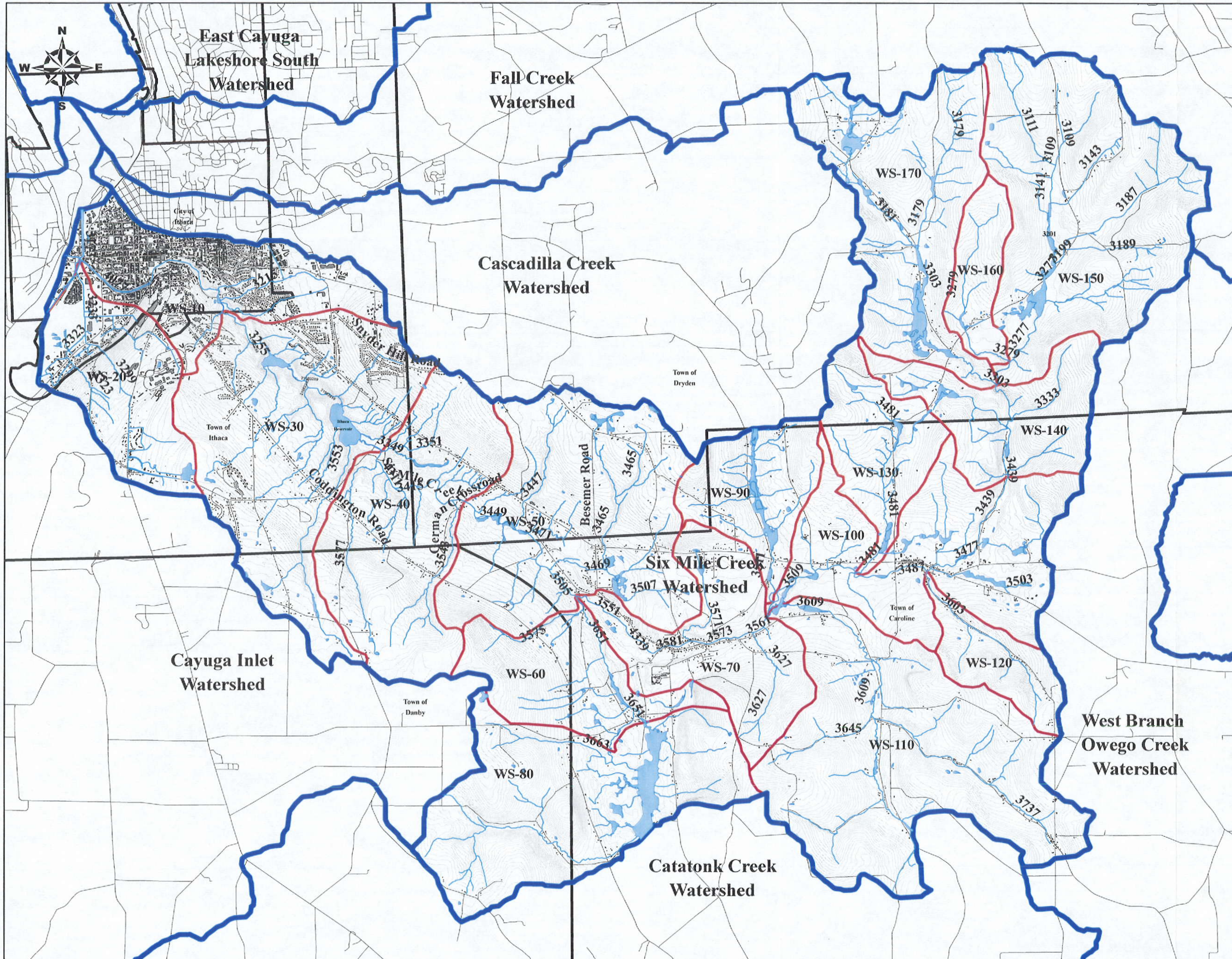
TABLE 4-1
Summary of Subwatershed Areas – Six Mile Creek

Watershed Designation	*Watershed Area (ac)*	*Watershed Area (sq. mi)*
WS-10	1,704 acres	2.66 sq. mi.
WS-20	1,364 acres	2.13 sq. mi.
WS-30	3,194 acres	4.99 sq. mi.
WS-40	2,350 acres	3.67 sq. mi.
WS-50	3 029 acres	4.73 sq. mi.
WS-60	1,201 acres	1.88 sq. mi.
WS-70	1,608 acres	2.51 sq. mi.
WS-80	2,785 acres	4.35 sq. mi.
WS-90	993 acres	1.55 sq. mi.
WS-100	2,320 acres	3.63 sq. mi.
WS-110	3,723 acres	5.82 sq. mi.
WS-120	607 acres	0.95 sq. mi.
WS-130	982 acres	1.53 sq. mi.
WS-140	1,238 acres	1.93 sq. mi.
WS-150	3,369 acres	5.26 sq. mi.
WS-160	548 acres	0.86 sq. mi.
WS-170	2,377 acres	3.71 sq. mi.

For analysis purposes, in addition to the stream reach references and subwatershed delineations, reach segments were defined along the length of Six Mile Creek. These are summarized in Tables 4-2 and 4-3 below. Figure 4-3 presents a schematic diagram of the sub-watershed structure.

TABLE 4-2
Summary of Stream Segment Designations – Six Mile Creek

Segment	*Description of Geographic Limits*	*Length*	*Description of Conditions*
1	Cayuga Inlet to Van Natta's Dam	1.95 mi	Highly channelized stable urban stream.
2	Van Natta's Dam to Burns Road	2.65 mi	Fairly stable area due to impounded water.
3	Burns Road to Banks Road	2.80 mi	High degree of lateral migration and erosion.
4	Banks Road to Middaugh Road	0.76 mi	Highly unstable with active headcut.
5	Middaugh Road to Valley Road near Route 330 in Brooktondale	1.36 mi	Stable channel segment u/s of headcut.
6	Valley Road near Route 330 in Brooktondale to Boiceville Road	2.08 mi	Stable bedrock channel with falls.
7	Boiceville Road to Creamery Road	0.77 mi	Stable low-gradient reach.
8	Creamery Road to Six Hundred Road	1.32 mi	Excessively steep segment with structural issues.
9	Six Hundred Road to Headwaters in Dryden	4.83 mi	Stable channel headwaters.



Legend

- Streams and Rivers
- Water and Wetlands
- Tompkins County Sub-Regional Watersheds
- Six Mile Creek Sub-Watersheds
- Town Boundaries

Source: Tompkins County GIS

Six Mile Creek Watersheds

Flood Mitigation Needs Assessment

Date: September 2005	Sheet: Figure 4-2
Scale:1:60,000	

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SIX MILE CREEK SUB-WATERSHED STRUCTURE

FIGURE 4-3

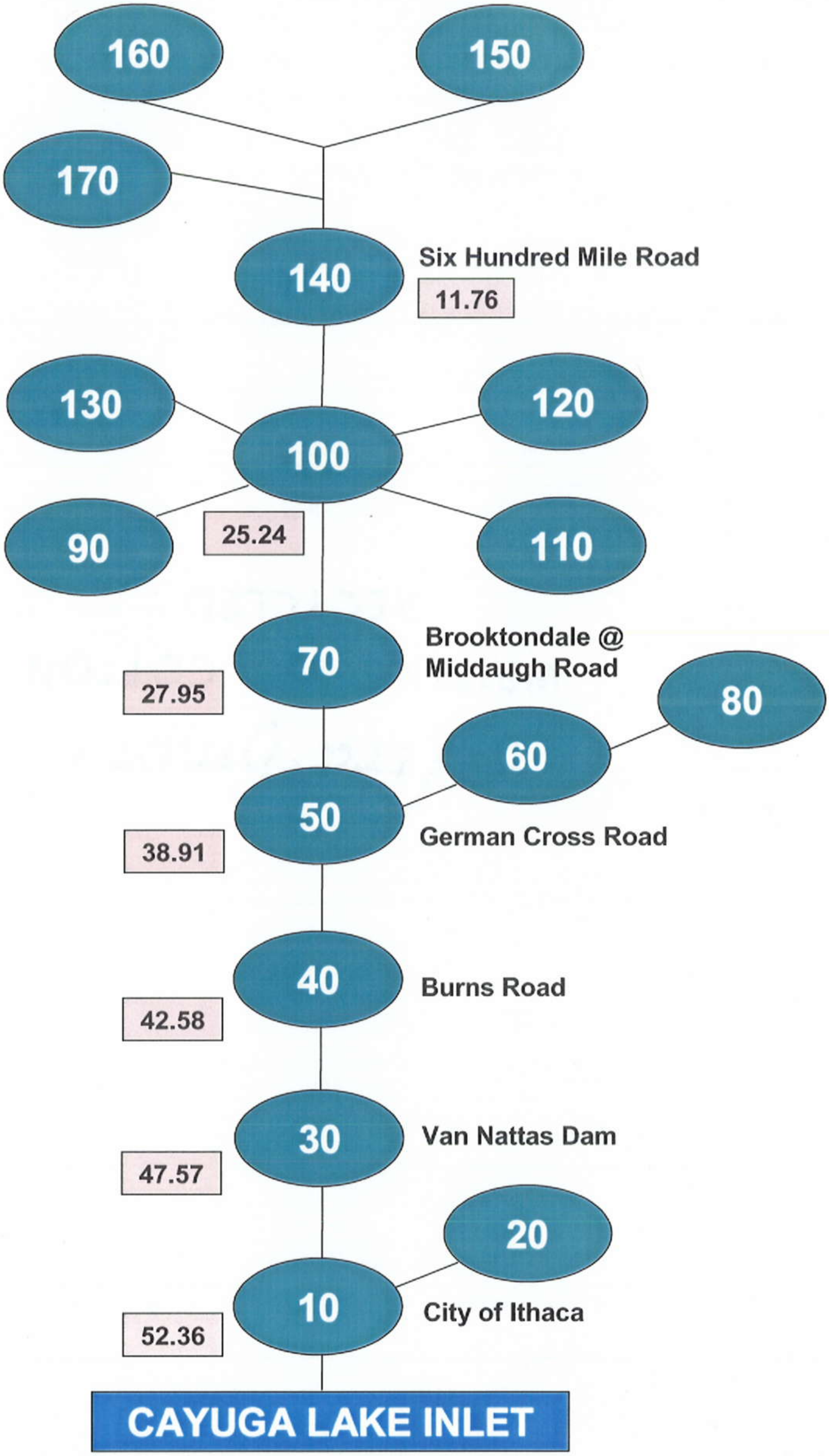


TABLE 4-3
Correlations of Subwatersheds to Stream Segments – Six Mile Creek

Segment Number	*Description of Geographic Limits*	*Incremental Contributing Subwatersheds*
1	Cayuga Inlet to Van Natta's Dam	WS-10, WS-20
2	Van Natta's Dam to Burns Road	WS-30*
3	Burns Road to Banks Road	WS-30*, WS-40, WS-50*
4	Banks Road to Middaugh Road	WS-50*
5	Middaugh Road to Valley Road near Route 330 in Brooktondale	WS-50*, WS-60, WS-70*, WS-80
6	Valley Road near Route 330 in Brooktondale to Boiceville Road	WS-70*, WS-90, WS-100*, WS-110
7	Boiceville Road to Creamery Road	WS-100, WS-120, WS-130
8	Creamery Road to Six Hundred Road	WS-100*
9	Six Hundred Road to Headwaters in Dryden	WS-140, WS-150, WS-160, WS-170

*Indicates that only a portion of the watershed drains into the stream reach.

4.2 *Terrain*

Six Mile Creek flows in a U-shape from its headwaters in a southwest, west, and then northwesterly direction into the south end of Cayuga Lake via Cayuga Inlet. The terrain in the watershed that contributes to approximately 19 miles of the main channel of Six Mile Creek is quite diverse, ranging from broad flat expanses in the Slaterville Springs area, to markedly steep side slopes with a non-existent floodplain in portions of Ithaca. In some reaches, the creek has downcut through the former clay and silt lake deposits down to the underlying till and bedrock.

The highest elevations in the watershed occur at around elevation 1600 to 1900 feet NGVD along the northern and southern perimeters. Cayuga Lake is the low point in the watershed, with normal water surface at elevation 382 feet.

4.3 *Existing Land Uses within the Six Mile Creek Watershed*

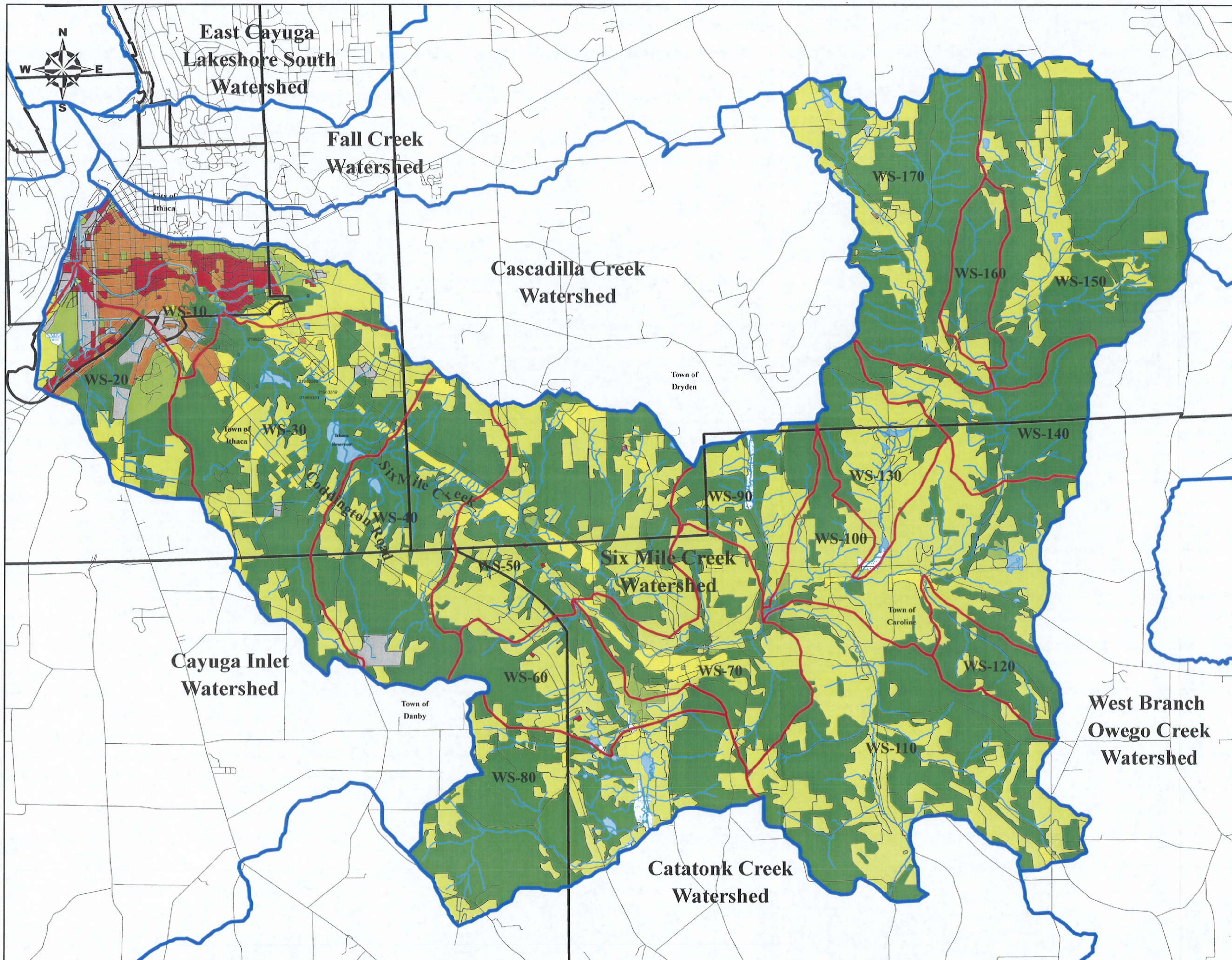
A great deal of information and insight can be gained from evaluating existing land uses in a watershed, comparing them with historic land uses, and projecting possible future land use changes. The latter can become a complex issue when dealing with multiple forms of zoning (or lack thereof) within different governmental and jurisdictional territories. Ideally, future land use should be governed and guided by effective land use planning along with the adoption and adherence to complementary regulations.

In many instances, land use has evolved based upon topography, terrain, and proximity to water resources. For instance, existing and historic agricultural uses tend to occur in areas with fertile soil types, relatively flat land, and proximity to irrigation supplies. In steeply sloped areas, one would expect a different type of development, perhaps sporadic single homes set amidst large forested areas.

The history of land use in the Six Mile Creek area is typical of many other areas in the northeast United States. The first land use activities of European settlers consisted of clearing the forests for fields and pastures on small farms. Agricultural land use increases runoff by removing the natural vegetation and its resulting forest litter and porous humus soils that help retain water. Further, surface water storage is reduced by repeated plowing and smoothing of the land. Farmers also built ditches to drain wetlands and dry out their fields. Tilling of agricultural fields also contributed to surface erosion.

Current land use in the Six Mile Creek watershed is largely forest cover, including three areas of protected state forest land, and moderate amounts of agricultural and residential uses. Overall, the density of development is quite low, and severe impacts caused by urbanization have not occurred in the watershed.

Figure 4-4 presents land use within the Six Mile Creek watershed based upon 1995 GIS mapping.



Legend

Watersheds

- Tompkins County Sub Regional Watersheds
- Six Mile Creek Sub-Watersheds

Landuse

- Agricultural Land
- Central Business District
- Open Space (Golf Course and Cemeteries)
- Forested Land
- Light Industrial
- High Density Residential
- Low to Medium Density Residential
- Utilities
- Wetlands
- Waterbodies
- Town Boundaries

Source: Tompkins County GIS

Six Mile Creek Landuse (1995)

Flood Mitigation Needs Assessment

Date: September 2005	**Sheet:**
Scale: 1:60,000	**Figure 4-4**

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Urban Areas – The only significant urban area is sub-basin WS-10, representing the City of Ithaca. This basin is intensely developed with residential, commercial, and industrial uses as well as transportation facilities. Slopes range from mild in downtown areas and along Route 13, to very steep to the east. Portions of sub-basins WS-20 (Ithaca College area) and WS-30 (Route 79, Route 366) south of Cornell University are also urban. Urban areas have a high impervious cover, catch basins with storm drains, and high surface runoff rates.

Moderate Development – Portions of watersheds WS-20, WS-30, WS-40, and WS-50 have what can be described as moderate development with low density residential areas. WS-70 has a compact developed village at Brooktondale in the Town of Caroline, centered around a series of 19th century water powered mills.

Secondary villages of limited size are located within WS-100 along Route 79 at West Slaterville and Slaterville Springs. All of the moderately developed zones are relatively low density and of limited land area.

Rural – Large areas of WS-50, 60, 70, 100, 110, and 130 are dominated by open cornfield, pasture, and cropland. During the May 2003 inspection, relatively few tilled fields were observed, and most had temporary or permanent (grass) ground cover. Few areas of surface erosion, rills, or gullies were observed. Extensive forest (mostly second growth hardwoods) exist in watersheds WS-90, 120, 140, 150, 160, and 170. The overall pattern is stable forestland on the steeper slopes around the perimeter of the Six Mile Creek watershed, with agricultural land in the valley bottoms and flatter uplands such as in WS-150 and 170. Watershed WS-90 is noteworthy because it follows a very low gradient glacial through-valley with significant wetlands.

The watershed's hydrologic regime is reflective of rural land uses with limited impervious cover and formal drainage systems. The landscape has been previously cleared and is currently returning to hardwood forest as farm land is abandoned. The watershed has good to excellent ground cover with minimal exposed soils. The few exceptions are active fields that are being tilled in preparation for spring planting and the large sand and gravel mining operation in WS-70 as well as an area near Middaugh Road and Brooktondale Road (old Route 330) at a self-storage facility, where fill (comprised of earthen material as well as tires, concrete blocks, etc.) has been placed directly adjacent to the streambank.

4.4 *Water Quality*

The southern basin of Cayuga Lake is included on New York State's *Priority Water Bodies List*, primarily because of the prevalence of silt and sediment. Southern Cayuga Lake is also included on the 303(d) list of impaired water bodies requiring a watershed approach to restoration. Six Mile Creek, located within the southern Cayuga basin, is noted for its extensive deposits of fine grained glacial drift that are actively and, in some cases dramatically eroding. However, there are no permitted wastewater discharges to Six Mile Creek.

4.5 *A Review of Past Studies on Six Mile Creek*

Six Mile Creek has been the subject of numerous study efforts, including academic studies affiliated with Cornell University. One such study (Nagle and Fahey) analyzed the proportional contributions of stream bank and surface sources to define sediment loads in streams of the southern Cayuga Lake Basin and other nearby watersheds. The study notes that many stretches of the stream below Brooktondale are characterized by slumping hillslopes and large eroding banks above the channel. Even forested slopes with minimal human impact exhibit this instability. In fact, extensive radionuclide testing indicates that the sediment load from bank erosion along Six Mile Creek is 82% of the total load, whereas surface erosion load accounts for only 18%.

Nagle and Fahey report that sediment loads in streams of the southern Cayuga watershed are not unusually high compared to the rest of the Northeast. However, high levels of bank erosion are occurring in response to channel incision, valley filling, and changes in stream channel morphology.

The Six Mile Creek channel is laterally unstable in some areas, particularly upstream of German Cross Road in the Bethel Grove section of Dryden, with rapid channel migration and re-establishment of meanders. This instability is coupled with channel degradation or down-cutting by several feet in some areas, resulting in an incised channel. A new floodplain has developed that is several hundred yards wide and significantly lower than what is thought to be the original floodplain elevation (Karig, et. al., 1995). The ground water table has been reported to have declined proportionally.

Field conditions suggest that the observed stream degradation (and subsequent aggradation) has occurred previously in Six Mile Creek, with the conversion of the watershed to agricultural uses in the 19th and early 20th centuries and the subsequent reduction in agricultural land uses through the 20th century, leading to reforestation and the associated degradation. Similar trends have been observed elsewhere in the eastern United States.

In the summer of 1994, the Tompkins County Soil and Water Conservation District conducted an inventory of the Six Mile Creek and its tributaries for the purpose of identifying areas of critical streambank erosion. Their study evaluated over 13 miles of main stem and almost 11 miles of tributaries (out of a total tributary length of approximately 39 miles). Erosion and deposition were calculated using the "*New York Procedures for Calculating Streambank Erosion*," developed by the New York State Natural Resource Conservation Service (formerly the Soil Conservation Service). The method quantifies streambank erosion and does not consider contributions from surface erosion or those from individual storm events or unnatural disturbances to banks and stream flow.

The Soil and Water Conservation District's inventory identified over 266 eroding banks on the main stem of Six Mile Creek, with an additional 676 eroding banks on the inventoried tributaries. Approximately 50 of the main channel banks and 80 of the tributary banks were classified by the District as being "critical" (i.e. those where erosion is or will affect man made structures or those that have a recession rate that is greater than 0.3 feet per year and were therefore categorized as contributing significant amounts of sediment load to the stream). The District's estimated cost to stabilize all eroding banks in the watershed totaled $848,000.

Many of the sites that were identified during the 1994 inventory are naturally occurring erosion and are due to the local geology and evolution of the watershed. It is difficult to ascertain from the 1994 inventory which type of erosion was occurring at the different sites. It is also important to look at the sub-watershed within which erosion is occurring to gain a broader perspective of the dynamics that are driving the system.

The Cayuga Lake Watershed Intermunicipal Organization also conducted a road bank and stream bank inventory from May through August 2000 wherein visual surveys were performed to obtain information to rank the erosion potential within the watershed. A visual survey was performed on all roads in the Cayuga Lake watershed (including those within the Six Mile Creek watershed) and road bank erosion was categorized as moderate, severe, or very severe.

The road banks in the Six Mile Creek watershed were identified as an area of concern. Numerous sites within the watershed were documented as moderately eroded, with many sites classified as severely eroded. Eight road ditches were classified as very severe.

Visual surveys were also performed by the Cayuga Lake Watershed Intermunicipal Organization on each tributary to Cayuga Lake and the erosion potential of each sub-watershed was ranked. The Six Mile Creek stream inventory included 55 sites, most of which showed evidence of significant streambank erosion.

The level of detail contained in the published documentation on the road bank and stream bank inventory by the Cayuga Lake Watershed Intermunicipal Organization did not permit a direct comparison to the field investigations and findings of the subject study. However, the study findings are consistent with historic observations as well as more recent investigation of conditions within the Six Mile Creek watershed.

Past inventories of erosion along Six Mile Creek are somewhat dated, particularly in light of the maintenance schedules of roadside ditches. Many areas that were previously subject to erosion have since stabilized, while other ditches that have been more recently maintained represent new sources of erosion. Incorporation of check dams and hydroseeding in the routine maintenance of drainage ditches in the future would help to reduce maintenance related erosion.

4.6 Hydrology of Six Mile Creek

Surface water hydrology is the quantitative study of the presence, form, and movement of water in and through the drainage basin. The primary independent variables affecting runoff are precipitation, watershed area, surficial geology, and slope. Dependent variables that change over short and intermediate time spans include vegetative cover, land use, wetland and floodplain water storage, reservoir size and volume, water diversion for irrigation or municipal use, and beaver dams.

For the purpose of studying bank erosion, sediment transport, and flooding, the primary interest is in peak stream flows due to intense precipitation, sometimes in combination with snow melt. It is the peak flood flows that shape and form the river channels, scour the banks, and carry the majority of sediment. Subsequent storm runoff events, perhaps up to the mean annual flood, also convey sediment and tend to dominate the formation of the inner channel dimensions, bars, pools, and riffles. Monthly mean stream flow rates are a good indicator of seasonal flow patterns that affect water supply, habitat, and recreation.

A watershed's stream flow rate can be obtained or estimated using several different techniques, including direct measurement, use of surrogate gauge data in nearby watersheds, physical deterministic computer models, statistical or stochastic analysis, or empirical techniques.

Within Six Mile Creek, direct measurement is possible via the U.S. Geological Survey (USGS) stream flow gauging station located at German Cross Road in Bethel Grove. This gauge was installed in cooperation with the City of Ithaca. A second gauge was installed along the creek in 2002. The Bethel Grove gauge has only been active since 1995, so only limited data is available. Consequently, longer duration regional gauges were also reviewed to learn about broad trends and patterns. Table 4-4 presents gauge data based on the published record at Bethel Grove, from 1996 through September of 2001.

TABLE 4-4
Summary of USGS Stream Gauge Data at Bethel Grove – Gauge #04233300

Year	*Average Annual Stream Flow (cfs)*	*Average August Stream Flow (cfs)*	*Peak Stream Flow (cfs)*	*Minimum Stream Flow (cfs)*
1996	102 cfs	47 cfs	2,700 cfs	8 cfs
1997	41 cfs	10 cfs	3,030 cfs	7 cfs
1998	62 cfs	10 cfs	1,180 cfs	8 cfs
1999	44 cfs	4 cfs	2,590 cfs	2 cfs
2000	66 cfs	13 cfs	2,020 cfs	8 cfs
2001*	55 cfs	8 cfs	2,950 cfs	5 cfs
Average	***57 cfs***	***14 cfs***	***2,344 cfs***	***6 cfs***

*Data spans a partial year.

The watershed area at the gauge is reported by USGS as both 39.0 and 39.3 square miles. The mean annual flood, based on just five years of record, is 2,344 cubic feet per second (cfs), which is equal to 60.1 cfs per square mile and well above average for the glaciated northeast. The highest peak flow of 3,030 cfs occurred in 1997.

The adjacent Fall Creek watershed has a long term USGS gauge with data from 1927 that helps to define trends and patterns in the region. The most notable pattern is that there is no distinct change in peak runoff rates over the period of record. Unusual peak flows occurred in 1935 (15,500 cfs), 1982 (11,900 cfs), and 1996 (9,450 cfs). All other peaks were uniformly distributed and below 6,000 cfs. The plot of the peak annual flow is quite consistent.

Low stream flow is primarily a function of precipitation patterns, land use and runoff characteristics, soil types, and geology. Six Mile Creek has a mean August flow of 0.35 cubic feet per second per square mile, which is typical for the Northeast. However, the minimum of the daily flows range from 2.0 to 8.0 cfs, which are inadequate for larger fish in the broad Six Mile Creek.

Beyond in-stream flow rates, aquatic habitat and fish are very sensitive to the corresponding stream channel depth and cross sectional area. Deep pools are necessary for fish survival during low flows. The channel structure in Six Mile Creek is wide and shallow along much of its length, with no concentration of flow. If the channel had a more well defined thalweg (i.e. the deepest portion of the channel), it would be more conducive to aquatic habitat during low flows.

5.0 *Watershed Needs Assessment – Six Mile Creek*

5.1 *Overview of Field Investigations*

During the week of May 19 through May 23, 2003, Milone & MacBroom, Inc. project team members conducted a week-long field investigation of Six Mile Creek and its contributing watershed. All seventeen sub-watersheds were inspected to visually access the properties that could influence downstream surface runoff and sediment loads. In addition, topographic maps, aerial photographs, and GIS land use/cover data were reviewed prior to the initiation of field investigations.

The investigations targeted areas of previously identified problems as well as representative stream sections, natural and man-made control points (such as dams, natural falls, and reaches flowing over bedrock), and areas of extensive lateral migration. Numerous cross sections were surveyed in the creek to enable an analysis of channel geometry in stable sections of the creek.

5.2 *Stream Profile and Control Points*

Appended Figure I is a profile of the Six Mile Creek from its inlet at Cayuga Lake to the headwaters in Dryden. Cayuga Lake controls the most downstream elevation, at a normal water surface elevation 382 feet. Within the City of Ithaca, Six Mile Creek is channelized, with concrete vertical walls along much of this reach.

Van Natta's dam is located within WS-10 within the City of Ithaca. The spillway at Van Natta's dam is at elevation ±502 feet. Upstream of the impoundment, Six Mile Creek flows atop bedrock in a deep gorge along stream reference 3255 within WS-30. The bed elevation in this reach is estimated to rise from elevation ±500 feet up to about 550 feet, just downstream of the lower reservoir dam.

The 30-foot lower reservoir dam (at stream reference 3255 in WS-30) has a spillway elevation of 583 feet, according to USGS topographic mapping. Between the lower reservoir dam and the Ithaca Reservoir Dam (within WS-30) is an area of shallow bedrock. Approximate bed elevation in this reach ranges from 590 feet on the downstream end up to 640 feet just downstream of Ithaca Reservoir. The 60-foot Ithaca Reservoir dam (also within WS-30) has a spillway elevation of 704 feet.

The siltation dam (at stream reference 3349 in WS-40) has a spillway elevation of approximately 720 feet, based on USGS topographic mapping. Upstream of the siltation dam (downstream of German Cross Road), two natural gas pipelines crosses Six Mile Creek. The lower pipeline has been armored with rip rap, the elevation of which is unknown.

Two sets of natural falls occur in Brooktondale, referred to herein as the lower falls and the upper falls. The lower falls (at stream location reference 3581 within WS-70) are about 20 feet in height along a width of about 120 feet, with a plunge pool at the base. The upper falls are located at stream reference 3573, also within WS-70.

An old mill dam is located upstream in Brooktondale. A set of falls are located approximately 300 yards upstream of the mill dam, and another set of falls are located near Irish Settlement Road in Dryden, near a long bedrock gorge. Six Mile Creek at its headwaters approaches elevation 1,650 feet.

5.3 *Needs Assessment by Stream Segment*

5.3.1 *Segment # 1 – Cayuga Inlet to Van Natta's Dam*

This stream segment includes all of subwatersheds WS-10 and WS-20. The stream in this reach of Six Mile Creek has been channelized between Cayuga Inlet and Aurora

Street, with a linear alignment and vertical masonry, stone, and concrete walls. It is a non-alluvial channel with a bankfull width on the order of 90 feet, and a cobble bottom. Numerous storm drain outlets discharge to the creek in this reach. A narrow buffer zone exists along South Titus Road and numerous bedrock outcrops are visible, beginning at Aurora Street. A deep bedrock gorge extends up to Van Natta's Dam at Giles Street.

This stream segment is very stable due to the bedrock gorge and the channelized reach in the City of Ithaca, and therefore does not represent a high priority with regard to flood mitigation.

5.3.2 *Segment # 2 – Van Natta's Dam to Burns Road*

This stream segment includes a portion of subwatershed WS30 as well as stream reaches 3255 and 3349. It is dominated by deep bedrock gorge impoundments. Reach 3255 upstream from Van Natta's Dam to the Lower Reservoir is a deep, flat bottomed bedrock gorge in the Wild Flower Preserve. Trails provide easy public access to the scenic gorge and its bedrock channel. A recent landslide is visible on the left bank (looking downstream) of the gorge, most of the debris having been washed away. The lower reservoir is inactive.

Two significant landslides along the right (north) side of the reservoir have been major sediment sources in the past. An active slide behind the *Commonland Community Condominiums* is about 200 feet wide and 210 feet high. It is estimated to have released 15,000 cubic yards of material. Reach 3349 is an upstream low gradient extension of Ithaca Reservoir to Burns Road and appears to be a modern deposition zone in the reservoir's backwater.

Landslides are very rare on mature landscapes and the cluster along Six Mile Creek is indicative of very steep slopes and a deep valley. There are no readily available or affordable preventive measures to address these, except for the preservation of existing vegetation. Aside from the historic landslides that have occurred in this reach of the creek, the stream and watershed are not actively contributing significant amounts to downstream sediment load. However, suspended sediment from further upstream does pass through this segment.

5.3.3 <u>***Segment # 3 – Burns Road to Banks Road***</u>

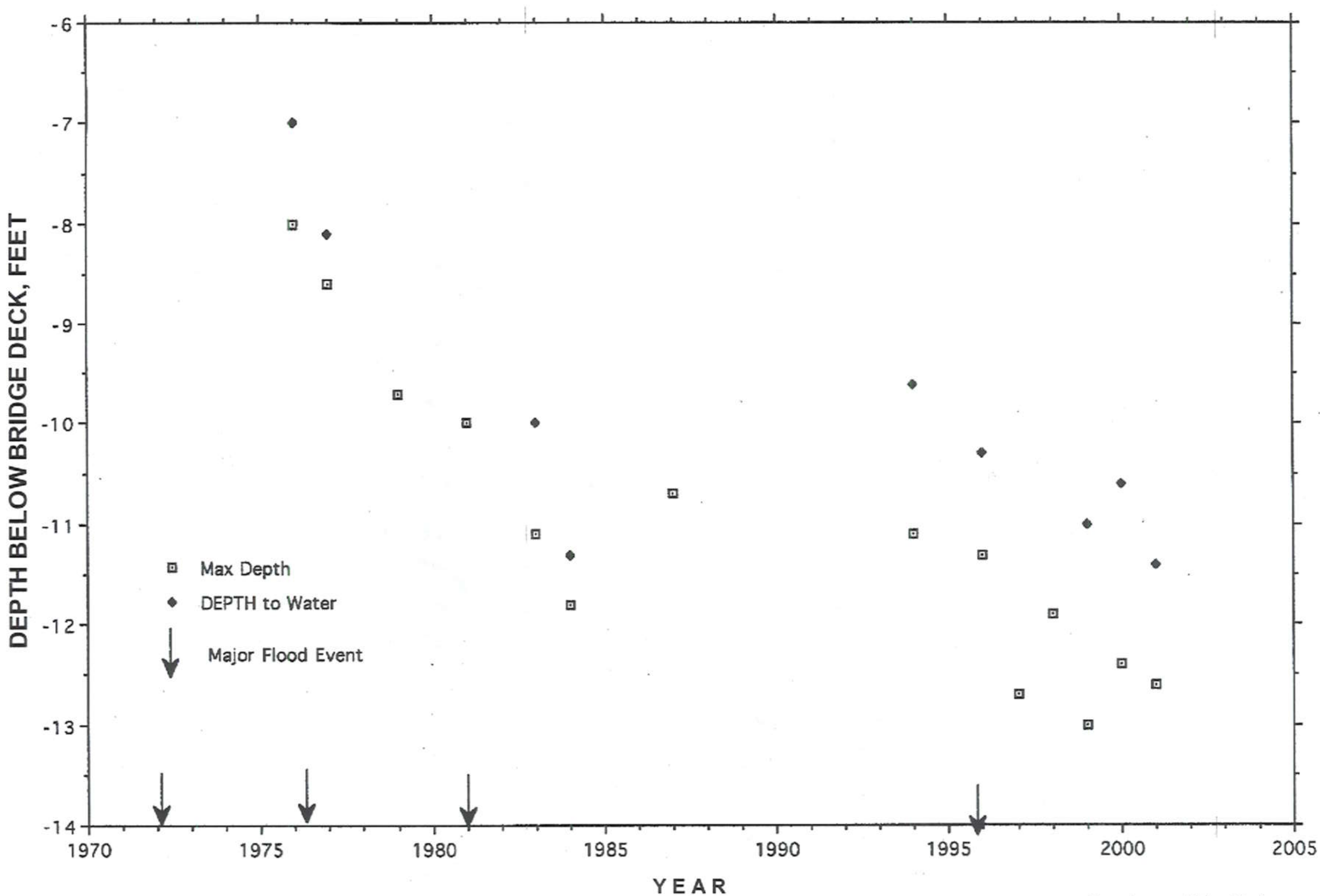
This river segment includes a portion of subwatersheds WS-30 and WS-50, and all of WS-40. The reach is of great interest because it has extensive evidence of large scale past degradation (±100 years) and now appears to be reaching an equilibrium slope. The channel bed is characterized by long runs with few riffles and pools, and no significant rapids. Several low residual knick points are still active but are atypical.

The previous degradation at the German Cross Road bridge has been well documented by Dr. Karig, a retired geology professor at Cornell University. His measurements indicate the streambed elevation declined by five feet over a period of 25 years. Measurements conducted during field investigations indicate no significant degradation since 2000. Figure 5-1 depicts a plot of the channel depth over time below the bridge at German Cross Road.

Most of the channel bed is covered with a dynamic natural armor of three- to 10-inch rock fragments, most of which are a thin strata of shale, resembling shingle or flagstone. A high percentage of the material is embedded in a gravel matrix, providing good stability but poor habitat. This material is deceptive, as it has low volume and weight in proportion to its D_{50} size. This is relevant, since volume and weight are important components in the evaluation of shear stress for stability.

SIX MILE CREEK AT GERMAN CROSS ROAD
DEPTH OF CHANNEL BELOW BRIDGE DECK

FIGURE 5-1



Courtesy of Dr. Karig

In traditional "pebble count" techniques, the pebble count dimension is assumed to be equal to the width of the pebble or stone. That dimension is used to estimate sphere diameter (i.e. stone width is assumed to be equal to stone length), which is in turn used to calculate the weight of the stone. When substrate material is not uniform in diameter, the length is not representative of the diameter of the stone and the resultant computation of weight and/or volume. In Six Mile Creek, therefore, conventional pebble count techniques would be misleading.

The channel reach from Burns Road to Banks Road has a high degree of sinuosity, with large gravel and cobble point bars with sparse vegetation. Using the Brice classification system, it is an equal width sinuous channel. Using the Watson (1984) Channel Evaluation Model, it is Class V. The degradation has exposed an interesting soil profile consisting of shallow topsoil, modern alluvium, glacial lake silt and clay, and glacial till.

Inspection of this reach indicates that having already approached an equilibrium slope, it is now widening and forming a second floodplain, leaving the alluvium of the past floodplain as a terrace. The evidence includes increased width-to-depth ratios (compared to upstream reaches), wide point bars, sinuous alignment, and active bend erosion on only one bank at a time.

A gas pipe crossing the river about 600 feet upstream of the siltation basin is reported to have been previously exposed by degradation and was observed to have been armored with riprap and a grade control sill. A second gas pipe crossing was found approximately 2,000 feet downstream of German Cross Road and the pipe is exposed. It is a hazard and should be stabilized immediately.

Dr. Karig's reports (1995) and MMI inspections confirm that the channel upstream of German Cross Road migrated laterally by approximately 100 feet over 25 years, with a continuing bank erosion and point bar/floodplain development. One would expect a cessation in degradation, a continuing increase in sinuosity and bank erosion, coupled with decreasing bed load sediment transport.

5.3.4 *Segment # 4 – Banks Road to Middaugh Road*

This river segment includes a portion of subwatershed WS-50. The segment upstream of Banks Road is a classic Simon Class IV scenario, with very active channel degradation and is just beginning the widening phase. The steeper gradient, multiple knick points, raw banks, and multiple mass failures attest to ongoing degradation.

The narrow point bars and lower percentage of embedded material both suggest continuing instability and lack of aggradation. This segment is a sediment source, with probable increasing rates of bank erosion. An anabranched channel has formed at the Whitham property along Brooktondale Road (old Route 330), apparently stimulated by a beaver dam. Other headcuts lower in this reach appear to have been at least temporarily stabilized at clusters of glacial boulders, some of a non-native, unusual reddish granite. If not controlled, degradation will accelerate in the next upstream segment towards Brooktondale.

5.3.5 *Segment # 5 – Middaugh Road to Valley Road near Route 330 in Brooktondale*

This river segment includes a portion of subwatersheds WS-50 and WS-70, and all of WS-60 and WS-80. This fairly straight river segment has two distinct faces. The first (downstream) portion is a continuation of the active headcutting channel found below Middaugh Road, with low steep banks and large trees down. Well defined bend pools and riffles are present, unusual for this river, not yet destroyed by degradation. The largest fish observed were in this segment, along with a large water snake. This occurrence is due to the fact that this segment is providing better habitat, with less incised and less regular streambed. Low gradient wide and shallow reaches generally provide poor habitat.

The floodplain and riparian zone on the right bank is being filled near Middaugh Road, with earth, demolition debris, tires, and trash, with no erosion controls or buffer. The upstream portion of the segment is a straight equal width channel with limited encasement. The bend at River Road has been rip rapped and is stable. The channel bed has a higher sand content than elsewhere, and the lake bottom clay soil state is barely visible at the bottom of some fresh cut banks. Full exposure of the clay has not occurred yet. But it will.

5.3.6 *Segment # 6 – Valley Road near Brooktondale Road in Brooktondale to Boiceville Road*

The Village of Brooktondale in the Town of Caroline is an 18th to 19th century industrial site with several low stone dams that powered mills. Six Mile Creek flows within a bedrock gorge with steep near vertical walls that are five to 30 feet high. This river segment includes a portion of subwatersheds WS-70 and WS-100, and all of WS-90 and WS-110. The channel is stable with minimal substrate.

A recent partial dam failure in this reach (lowered crest) released a low volume of impounded sediment, filling local downstream pools. Steel sheeting and gabions have been used to reinforce steep earth banks that back bedrock at this structure.

The small mill dams are fish blocks and they are filled with sediment. The run-of-the-river structures have a low trap efficiency and would have little if any impact on downstream suspended concentrations, even if dredged.

5.3.7 *Segment # 7 – Boiceville Road to Creamery Road*

This river segment includes a portion of subwatershed WS-100 and all of WS-120 and WS-130. The grade of this slightly sinuous, equal-width channel is controlled by bedrock at Brooktondale that stabilizes and prevents degradation. The downstream reach is influenced by backwater from a dam in Brooktondale and has some riparian wetlands, as well as weak points (i.e. point bars that are not well defined, with low amplitude meanders that would be expected to grow in time) and alternate bars. Much of the channel in this reach is remote and was not inspected on foot.

Previous bank erosion at a residential property was repaired using a vertical retaining wall consisting of five to six stacked courses of somewhat cubical rough cut stone, without mortar or tiebacks. No conventional foundation is apparent. This wall is reported to have been installed ±1997 and blew out in either 1998 or 1999. Portions of the wall have since collapsed, leaving large stones in the river and an earth slump. The rocks are working effectively as a deflector. Additional measures at this site that may be considered include excavating along the left (eastern) bank in combination with placing another course of stone on the lower wall of the right (western) bank and stepping it down with boulders downstream of the meander.

5.3.8 *Segment # 8 – Creamery Road to Six Hundred Road*

Proceeding farther upstream, the banks of Six Mile Creek are higher, with increased incision. This river segment includes a portion of subwatershed WS-100. The channel at Slatersville Springs at the Tutton property has increased and scoured one bank where a retaining wall has failed. This is a Simon Class IV channel and a Rosgen Type F.

The incised 60-foot wide channel is disconnected from its former floodplain, concentrating water with higher velocities. Smooth rigid bank protection will increase velocities and exacerbate degradation. A preferred solution in this reach would be to create a new larger floodplain at a lower grade and add channel roughness.

The right bank of Six Mile Creek was inspected at the Tutton property to view a previous bank erosion site that has been repaired. The top of bank width is approximately 60 feet, with a bank height of 10 feet and a typical flow depth of one to two feet. The slightly sinuous channel has a gravel and cobble bed, two feet of bend scour, and an estimated velocity of two to three feet per second.

Further upstream along Segment #8 near Slaterville Road is a site known as the Barille site, which has also experienced bank erosion on both banks. Field conditions suggest that the stream is attempting to achieve more sinuosity to overcome its excessive energy. There is no real floodplain in this area and the channel is incised. A restoration effort is proposed for this area under coordination by the Soil & Water Conservation District. This site would be a good candidate for single wing deflectors, placement of boulders or boulder clusters, and vortex weirs. However, bank-to-bank vortex weirs are not advisable here, as they would serve to back water up on the upstream side.

The channel upstream of Route 79 parallel to Six Hundred Road has a narrower bankfull width due to its smaller watershed and steeper gradient. This reach has several active knick points that are deepening the channel. Widening is occurring here and meanders developing. This dynamic activity, probably stimulated by the 1982 and 1996 floods, appears to cause no harm other than generating moderate levels of sediment, and no nearby downstream aggradation problems are obvious. Vortex weirs or sills could be used to curtail the natural degradation if so desired.

A long precast concrete mass retaining wall along the right bank of Six Mile Creek was inspected at the Moesch property in this reach. The wall is comprised of four courses of large rectangular concrete block (approximately two-feet by two-feet by eight-feet) stacked vertically on the outside of a bend. This gravity wall is supporting the toe of a ±100-foot high slide area composed of steep un-vegetated coarse outwash soils. Repeated landslides and bank repairs have occurred at this site.

The original two-block high wall was built in 1989; damaged and repaired in 1992; failed again in 1997/98; and repaired again in 1998, with a partial planting along the bank. The undated design sketches, probably from 1997 on *International Engineering Company* paper show no foundations or tiebacks. No known hydraulic or scour computations exist for this restoration effort.

The upper slope has some cohesion, with near vertical slopes and a visible seepage plane. The mid-bank area is at the angle of repose and is barren, while the lower bank is a colluvium deposit zone with some successional and planted vegetation. Despite the stark appearance of the vertical, unvegetated cliff, this site does not appear to be a significant source of sediment. A permanent solution in lieu of continued maintenance of the wall would be to physically relocate the creek to the east, away from the cliff. However, this would be a major and costly undertaking. On a much smaller scale, the blocks in the wall could be tied together and anchored to prevent frequent blow-outs.

5.3.9 <u>Segment # 9 – Six Hundred Road to Headwaters in Dryden</u>

This river segment includes subwatersheds WS-140, WS-150, WS-160, and WS-170. It consists of the headwaters of Six Mile Creek and is a low flow stable channel. A deep bedrock gorge with water falls and flat flumes (i.e. flat bedrock with broad, shallow water) is located east of a former tree farm, while further upstream is a low gradient first and second order pastoral channel through active agricultural areas.

5.4 Surveyed Cross Section Geometry

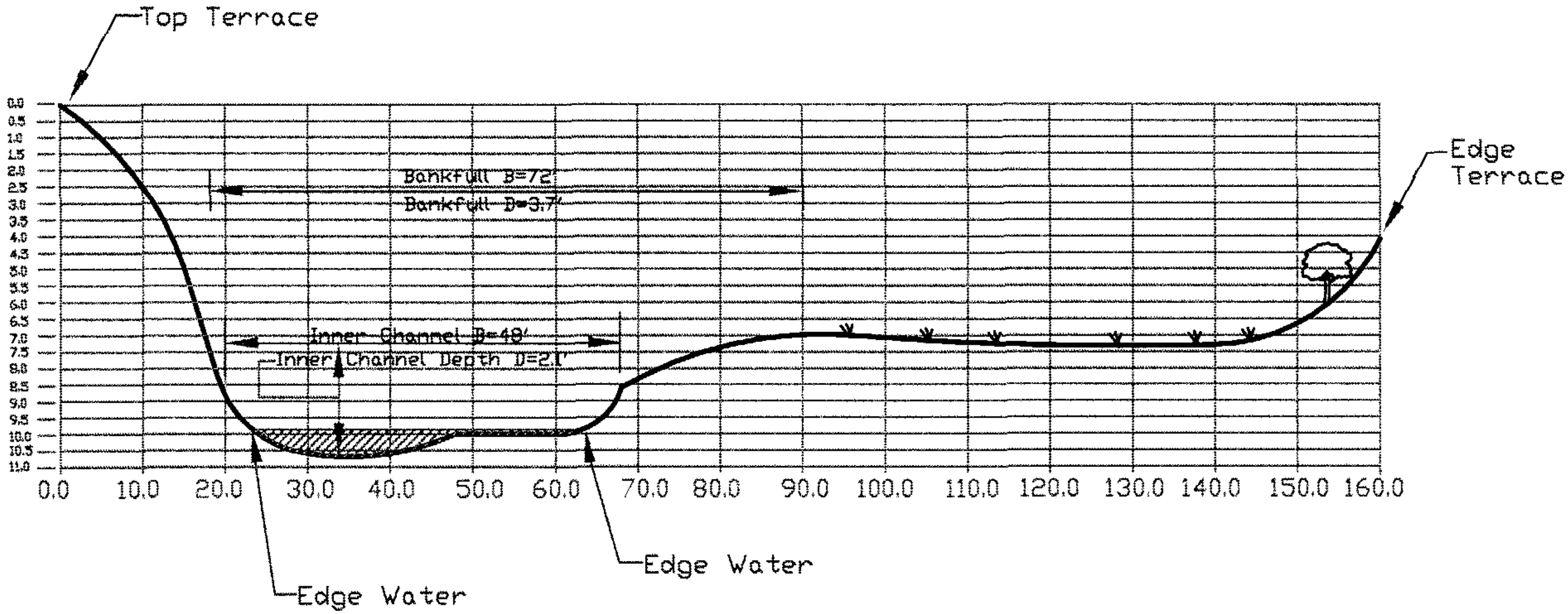
Several channel cross sections were surveyed by MMI with a transit and stadia rod to help document and classify the stream and check widths and depths versus regional data. The cross sections were selected to be representative of longer stream segments and were used as a guide for visual classification of non-surveyed areas. The cross section surveys included identification of the apparent "bankfull width and depth" and the channel slope using standard USGS (Leopold) and USFS techniques. They were intentionally placed at four different types of channel classes, and then compared with literature values. Cross sections are depicted in Figures 5-2 through 5-6. Data is presented in Table 5-1.

TABLE 5-1
Hydraulic Geometry of Selected Stream Segments – Six Mile Creek

Section	*Location*	*River Segment*	*W_{bF} (ft)*	*D_{bf} (ft)*	*W/D Ratio*	*$2xD_{bF}$ W_{bF}*	*Entrenchment Ratio*	*Rosgen Classification*
#1	3449 reach – Karig Site – German Cross Road	3	72	3.6	20.0	148	2.05	B3
#2	3471 reach – D/S Banks Road	3	55	2.8	19.6	94	1.71	B3
#3	3477 reach – Barille Site – Six Hundred Road	8	28	3.8	7.3	148	5.29	E3 (G3)

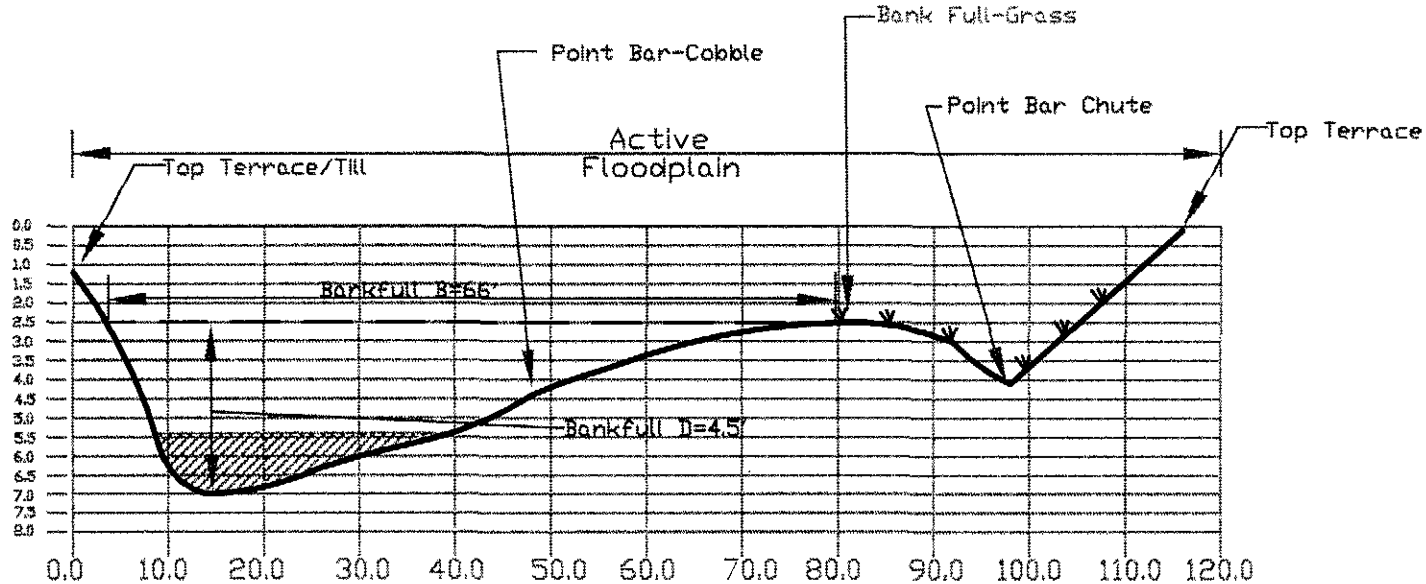
Note: The entrenchment ratio is approximated as width of floodplain @ 50-year flood (approximately equal to the elevation at two times the bankfull depth) divided by the width of the floodplain at bankfull depth.

The substrate material was inspected at each cross section, and selective particle measurements were taken. Detailed pebble counts and sieve tests were not performed, largely because the thin flat gravel and cobbles would not be described well by the popular but inaccurate "count" method and the sands are primarily limited to interstitial voids. The resistance to movement by individual stones is primarily a function of the their weight, which is often approximated by measuring their intermediate axis to find their equivalent diameter. However, the Six Mile Creek gravels and cobbles are generally the shape of a plate, so that simple pebble counts of equivalent diameter are not appropriate.



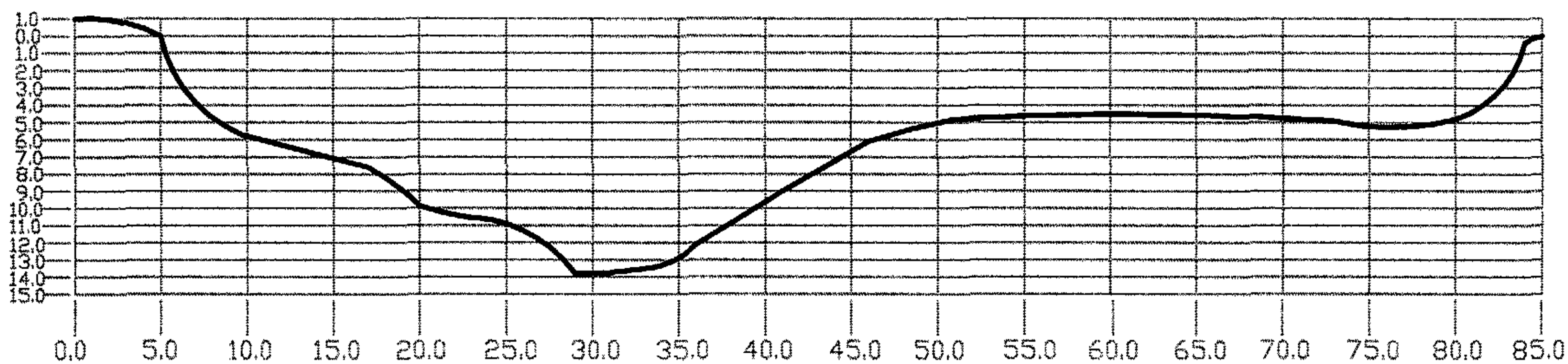
Karla Property
v/s German Crossroad

MILONE & MACBROOM, INC. Civil, Water Resource and Transportation Engineering - Landscape Architecture Surveying - Planning 716 South Main Street - Cheshire, Connecticut 06410 (203) 271-1773 - FAX (203) 272-9733	Six Mile Creek Tomkins County, New York	Reach 3449
	MMI # 2343-01-03	DATE: 9/5/03 SCALE: H: 1" = 20' V: 1" = 5' SHEET: Figure 5-2



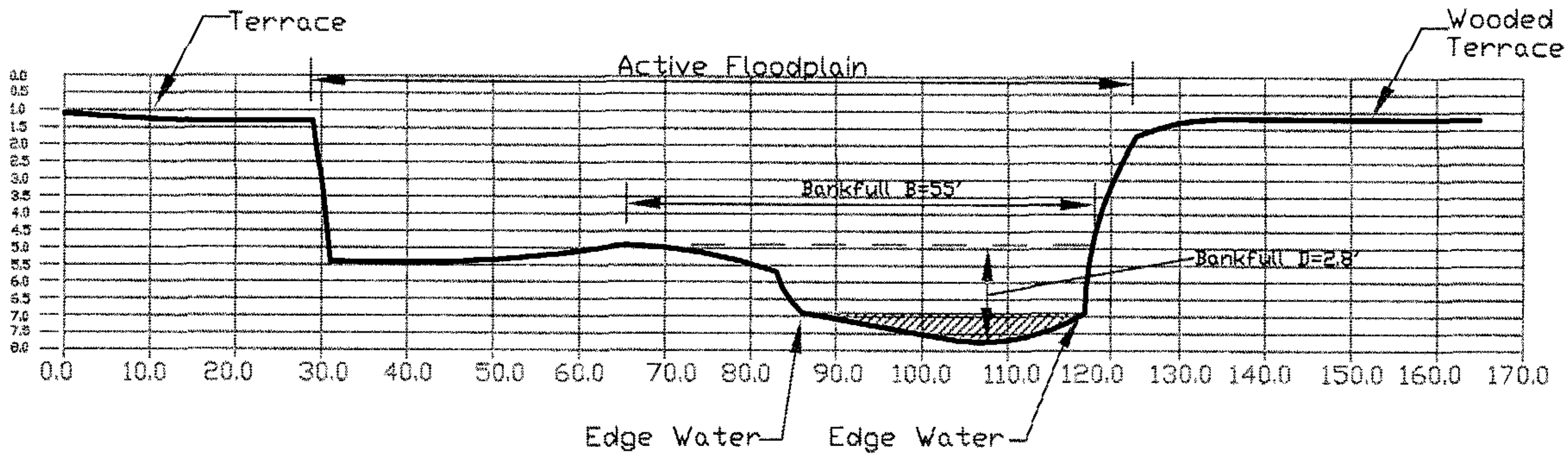
Bend Cross Section
Karlo Property

MILONE & MACBROOM, INC. Civil, Water Resource and Transportation Engineering - Landscape Architecture Surveying - Planning 716 South Main Street - Cheshire, Connecticut 06410 (203) 271-1773 - FAX (203) 272-9733	**Six Mile Creek** **Tomkins County, New York** **MMI # 2343-01-03**	**Reach 3449** DATE: 9/5/03 SCALE: H: 1" = 20' V: 1" = 5' SHEET: **Figure 5-3**



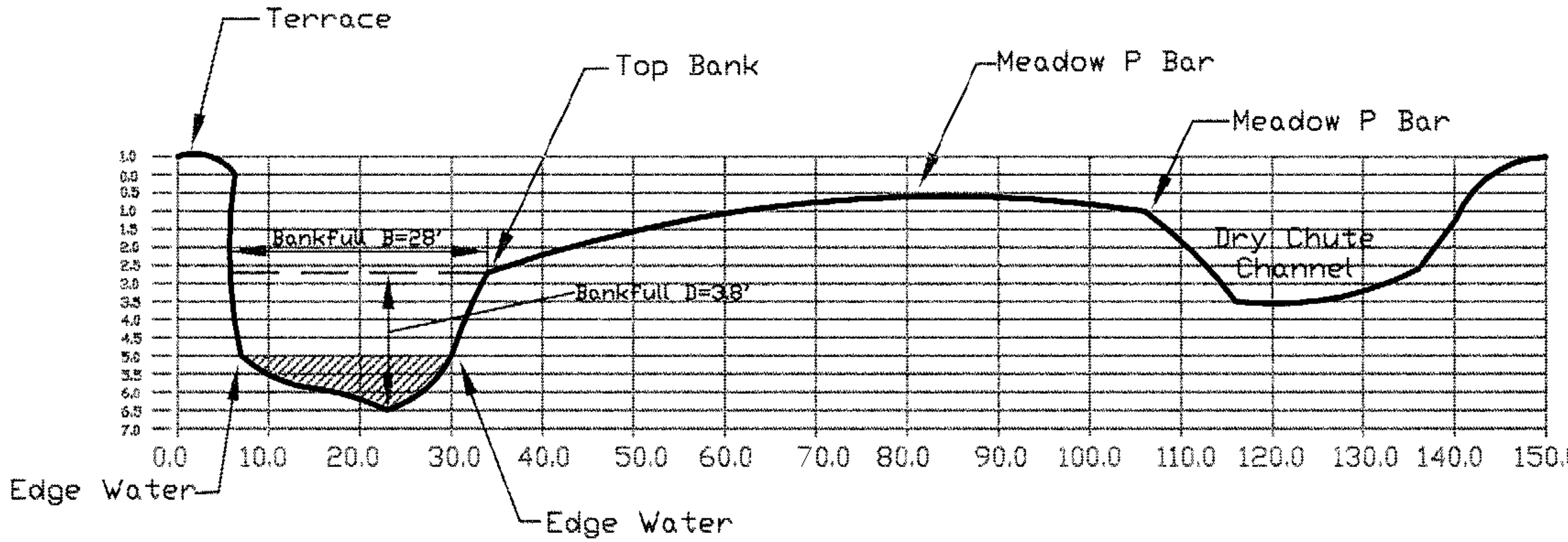
Gully Cross Sections
Karlg Property

MILONE & MACBROOM, INC. Civil, Water Resource and Transportation Engineering · Landscape Architecture Surveying · Planning 716 South Main Street · Cheshire, Connecticut 06410 (203) 271-1773 · FAX (203) 272-9733	**Six Mile Creek** **Tomkins County, New York**	**Reach 3449**
	MMI # 2343-01-03	DATE: 9/8/03 SCALE: 1" = 10' SHEET: **Figure 5-4**



River Cross Section
165 ft D/S Banks Road

MILONE & MACBROOM, INC. Civil, Water Resource and Transportation Engineering - Landscape Architecture Surveying - Planning 716 South Main Street - Cheshire, Connecticut 06410 (203) 271-1773 - FAX (203) 272-9733	**Six Mile Creek** **Tomkins County, New York**	**Reach 3471**	
	MMI # 2343-01-03	DATE: 9/5/03 SCALE: H: 1" = 20' V: 1" = 5'	SHEET: **Figure 5-5**



River Cross Section
Barille Site

MILONE & MACBROOM, INC. Civil, Water Resource and Transportation Engineering - Landscape Architecture Surveying - Planning 716 South Main Street - Cheshire, Connecticut 06410 (203) 271-1773 - FAX (203) 272-9733	**Six Mile Creek** **Tomkins County, New York** **MMI # 2343-01-03**	**Reach 3477** DATE: 9/5/03 SCALE: H: 1" = 20' V: 1" = 5' SHEET: **Figure 5-6**

Each of the cross sections was classified using the Rosgen system. The cross sections near German Cross Road and near Bank Road were both found to be moderately entrenched with moderate sinuosity, fitting the Rosgen B3 classification. However, the first section was unstable due to lateral migration and continual widening, while the second section was stable. A cross section was also surveyed at the active meander bend upstream of the Karig property to demonstrate the bend scour and point bar.

A cross section was surveyed between Slaterville Springs and Six Hundred Road in the Town of Caroline. This section was found to be a Rosgen F3 due to limited floodplain entrenchment. However, its true behavior characteristics are closer to a Rosgen G3 channel due to a pronounced low flow inner channel.

Recent studies in the Catskill region of New York by the NYCDEP provide the best available regional channel geometry data. While the Catskill data is not a good fit to Six Mile Creek, it is the best that is available. Those studies found that the local bankfull discharge that is assumed to dominate the channel size can be expressed as:

$$Q_{bf} = 62.96\,(DA)^{0.87}$$

Q_{bf} = bankfull discharge, CFS
DA = drainage area, square miles

Applying this to Six Mile Creek for Segment 3 at German Cross Road yields a discharge of 1,525 cfs compared to the measured mean annual flood (six years of record) of 2,344 cfs, a poor fit. This may be due to the short gauge record or different climate conditions.

The watershed area at German Cross Road is 39 square miles. The corresponding regional equilibrium channel bankfull width (W_{bf}) for this size watershed is 81.0 feet, slightly wider than the 72 feet surveyed by MMI, and much wider than the 55 feet measured near Banks Road where widening is in its earlier stages. The bankfull depth

(D_{bF}) computed with the NYCDEP regional equation is 3.1 feet, compared to the 3.6 and 2.8 feet measured by MMI for Six Mile Creek.

Cross section #3 was surveyed at the Barille site north of Route 79 and west of Six Hundred Road, an area with active channel head cuts and excessive slope, in the early stages of entrenchment.

The data in Table 5-1 indicates Six Mile Creek is narrower in the measured areas than one would expect based upon regional hydraulic geometry data. The conclusion of this evaluation, although limited in extent, is that Six Mile Creek has become incised vertically faster than it is spread laterally, and that one can expect further channel widening as per the classic Watson channel evolution model.

- <u>Rills</u> – Some examples were found on agricultural fields, and in wooded areas south of Coddington Road, but the number and density of observed rills is far lower than unglaciated terrain.

- <u>*Valley Side Gullies*</u> – Many valley side gullies were observed in the Six Mile Creek watershed between Coddington Road, Six Mile Creek, and north of Route 79 at Bethel Grove and Besemer. Specific reaches include 3447, 3465, 3577, 3553, 3543, and 3351. Several of these reaches were inspected and found to have very steep bed slopes that have eroded through till or lake bottom clay and have generally reached bedrock or have become armored with cobbles. Their widening and upstream migration were significant sources of sediment in the past. They all appear to be post-glacier features and were probably formed, or at least grew, after colonial era forest clearing. Several are deep enough to intercept perched groundwater and convert to perennial streams.

- <u>*Valley Bottom Gullies*</u> – Examples were found upstream of the siltation basin and upstream of Banks Road.

- *Entrenched Streams* – Entrenched channels occur in bedrock, such as in Brooktondale, and in surficial soils or in earlier sediment deposits. Six Mile Creek is an entrenched type of incised channel for much of its length.

5.5 Complex Response

The recent sediment deposition observed downstream of Banks Road and entrapped at the siltation basin and reservoir are at least partly the result of the channel's "complex response" as defined by Darby and Simon (1999). It is not the result of upland sheet erosion or urbanization, with minor contributions from winter road sand and roadside ditches.

The modern incision of Six Mile Creek from the reservoirs to Banks Road, and from Brooktondale to Creamery Road is essentially complete. Field evidence includes relatively low channel bed gradients, fresh growth of emergent and shrub vegetation on alternate and point bars, channel widening, and the beginning of increased sinuosity. However, the complex response occurs in the upstream reaches from Banks Road to Valley Road, and from Creamery Road to the north end of Six Hundred Road, which are now incising as the knick points move upstream. In addition, some lateral tributaries that have to cross the valley bottom are also incised. The sediments from the upstream and tributary erosion are accumulating in the already degraded and widening downstream channel, slowing or halting any further downstream degradation.

5.6 Slope and Sinuosity

The bed slope and sinuosity were measured for various segments along Six Mile Creek based upon use of GIS and USGS maps as well as aerial photographs. These data are presented in Table 5-2 and in Figure 5-7. The points on the graph represent stream segments 2 through 5, 6a, 6b, and 7 through 9. For each reach, the valley length, stream length, and change in elevation were used to calculate slope and sinuosity, as plotted in Figure 5-7.

TABLE 5-2
Segment Data – Six Mile Creek

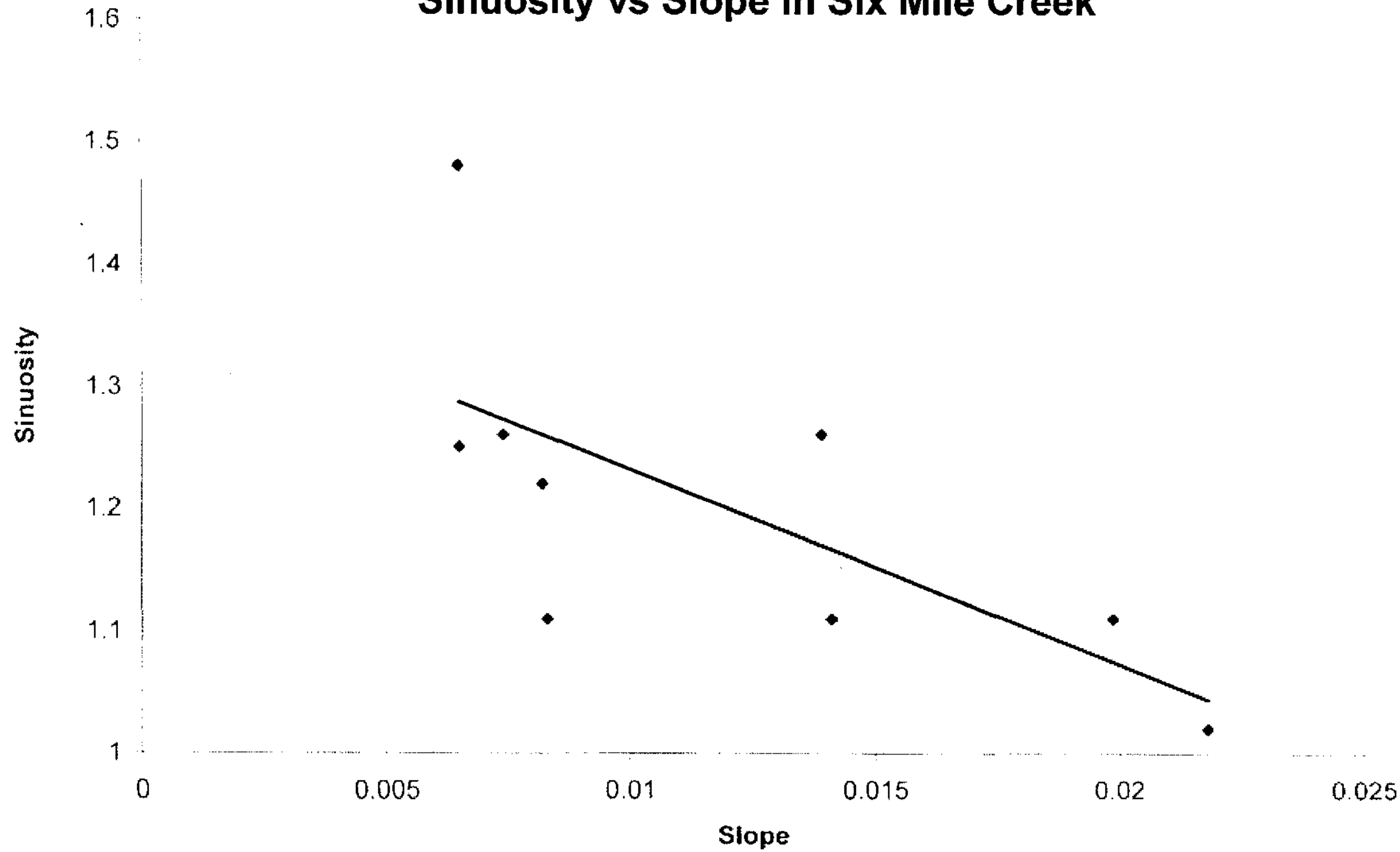
Segment	*Sinuosity*	*Slope*	*Comment*
1	N.A.	N.A.	Urban channel
2	1.11	0.0198	Bedrock gorge, dams
3	1.48	0.0065	Incised, widening
4	1.26	0.0074	Active knick points
5	1.11	0.0083	Few knick points
6A	1.02	0.0218	Bedrock gorge, dams
6B	1.25	0.0065	Incised, stable
7	1.22	0.0082	Slightly incised, widening
8	1.26	0.0139	Active knick points
9	1.11	0.0141	Stable, some bedrock

A river segment slope (i.e. change in vertical grade divided by horizontal length) is a good indicator of its velocity and sediment transport capacity, while the sinuosity is an indicator of the degree of channel meandering and maturity. Briefly, the normal trend is for river segments that are "geologically" young to be fairly steep and straight, while "mature" channels that have worn down the landscape towards an equilibrium condition have low gradients and a higher sinuosity with a curvilinear meandering pattern and fine grain sediments.

The data and field inspections reveal a river with several distinct facets. The first segment is the largely channelized, straightened, and armored channel in the area of the original river mouth delta, now occupied by the City of Ithaca.

Segment 2 has deep bedrock gorges with steep sides subject to landslides, with three dams forming impoundments. The bedrock and dams control the elevation of upstream segments. Segments 3, 4, and 5 are related to the bedrock control in Segment 2, and show a classic increase in slope in the upstream direction, with a decrease in sinuosity.

FIGURE 5 – 7
Sinuosity vs Slope in Six Mile Creek



Segment 6A at Brooktondale also has bedrock exposures, with an incised gorge. The channel repeats the sequence of completed incision just upstream of the bedrock segment, the active headcutting being further upstream above Route 79 at Six Hundred Road. In between, at the Tutton property in Caroline, the channel is partially incised and is in the widening stage of evolution where the sinuosity begins to increase. Thus the banks are being eroded and structural bank protection is of limited long-term effectiveness. As indicated in Section 3.3.8 of this document, a preferred solution in this reach would be to create a new larger floodplain at a lower grade and add channel roughness.

6.0 *Priority Issues and Recommendations – Six Mile Creek*

The most notable issue raised by the stakeholders of the Six Mile Creek watershed is ongoing erosion that is occurring in the watershed, along with the resulting turbidity of the water. Based on discussions and interviews with watershed stakeholders, as well as a review of the history of actions within the watershed, the highest priority concerns in Six Mile Creek center around the following issues:

Protection of property and infrastructure (i.e. roadways, bridges, pipelines, etc.). Widespread concern has been voiced from private property owners along the creek with regard to the loss of land and, in some cases, vulnerability of structures.

Protection of drinking water quality. Ongoing erosion in the creek and in the watershed regularly results in elevated sediment and turbidity in Ithaca Reservoir. This has management, treatment, and water quality implications.

Elimination of "unsightly" erosion occurring within the watershed. There is a general level of discomfort associated with the stark eroding banks along the Six Mile Creek.

Elimination of the sediment plume in Cayuga Lake during and following storm events. Water quality impairment has been documented in Cayuga Lake, resulting in its placement on the 303(d) list of water quality impaired waterbodies. The impairment is associated with the sediment plume into Cayuga Lake from the Cayuga Inlet, which is also a visual eyesore during periods of rain.

Other secondary issues include the practices of road sanding, aquifer protection, and the overall ecological health of the creek. In addition to addressing the aforementioned concerns, a common goal of establishing riparian buffers along the creek has been identified by numerous watershed stakeholders.

6.1 ***Priority Issue # 1 – Streambank Erosion***

With regard to streambank erosion, critical questions are:

- Should degradation be controlled?
- Would placement of bed controls in the creek to prevent down-cutting result in exacerbated lateral migration?
- Should the channel be relocated at the heavily eroding meanders?
- Should the steep tributaries be controlled?

Controlling degradation for the entire Six Mile Creek watershed through conventional means would be a daunting and cost prohibitive venture. Traditional approaches to river management are often limited in scope, prohibitively expensive, and environmentally unsound. The concept of managing the watershed and corridor as well as the river channel itself provides an alternate approach that allows each river function to be managed at the appropriate level. As such, bank stabilization techniques should be judiciously applied in priority areas to protect existing structures, private property, and infrastructure (i.e. bridges, gas mains, water mains, etc.).

Field conditions indicate that significant down-cutting has occurred along Six Mile Creek. In many locations, the creek has hit bedrock or till vertical control and the creek is now relatively stable. The exception is along Segment # 4 (Banks Road to Middaugh Road) where, if left unchecked, degradation will accelerate in the next upstream segment towards Brooktondale.

In many instances, channel relocation provides a more permanent, stable, and lower maintenance restoration alternative that provides environmental habitat benefits beyond erosion control. This approach is generally preferable over "spot repairs" such as riprap armoring or the erection of structural controls.

Both past and future mitigation efforts in the form of structural walls and other vertical barriers are likely to require continued maintenance and experience repeated failures. Rigid riverbank retaining walls should be designed by a qualified licensed Professional Engineer and should include a hydraulic analysis of velocity and scour impacts, as well as a stability analysis considering active earth pressures, hydrostatic pressure, surcharge loads, and foundation conditions.

Channel relocation in combination with creating an "artificial floodplain" can provide a highly effective fix. However, caution is warranted in designing restoration projects for sites that are not stable. For instance, the application of a geomorphic-based design such as Rosgen is a powerful tool. However, the methodology is not appropriate in many areas of instability.

The tributaries that feed Six Mile Creek traverse notably steep slopes and many show evidence of past down-cutting. However, the majority of those tributaries inspected by MMI had reached vertical control points and did not appear to be migrating laterally. Initial indications would therefore favor concentrating restoration efforts on the main channel of the creek.

The following priorities are recommended along the Six Mile Creek: The highest priority reaches include Segment 4 (from Banks Road to Middaugh Road) and Segment 8 (from Creamery Road to Six Hundred Road). Moderate priority reaches include Segment 3 (from Burns Road to Banks Road) and Segment 5 (from Middaugh Road to Valley Road near Route 330 in Brooktondale).

TABLE 6-1
Segment Restoration Priorities – Six Mile Creek

Segment	*Description of Geographic Limits*	*Description of Conditions*	*Priority*
1	Cayuga Inlet to Van Natta's Dam	Highly channelized stable urban stream.	Low
2	Van Natta's Dam to Burns Road	Fairly stable area due to impounded water.	Low
3	Burns Road to Banks Road	High degree of lateral migration and erosion.	Moderate
4	Banks Road to Middaugh Road	Highly unstable with active headcut.	High
5	Middaugh Road to Valley Road near Route 330 in Brooktondale	Stable channel segment u/s of headcut.	Moderate
6	Valley Road near Route 330 in Brooktondale to Boiceville Road	Stable bedrock channel with falls.	Low
7	Boiceville Road to Creamery Road	Stable low-gradient reach.	Low to Moderate
8	Creamery Road to Six Hundred Road	Excessively steep segment with structural issues.	High
9	Six Hundred Road to Headwaters in Dryden	Stable channel headwaters.	Low

Most of the inspected channel reaches along Six Mile Creek had unusually low levels of channel roughness with which to reduce flow velocities and provide structural habitat. A comprehensive program is recommended to increase channel roughness that would include the following measures:

- anchor or bury large woody debris in the banks;
- create boulder and log sills in the riverbed to form rapids and pools;
- install individual boulders and boulder clusters in the channel; and
- redefine the channel's thalweg.

Finally, the following site-specific recommendations are offered:

- The existing Six Mile Creek "knick points" between Banks Road and Brooktondale should be stabilized in-place as an interim measure to minimize further upstream incision.

- The bifurcated flow upstream of Banks Road at the property of Scott Whitham (reach #3505) should be redirected into the left channel and the right channel converted to a riparian wetland floodplain.

- The eroding river bank and stacked rock retaining wall failure at the Tutton property (reach #3487) in Slaterville Springs should be addressed by creating a floodway on the left bank and backfilling the channel near the wall to increase the waterway area and reduce velocities.

6.2 ***Priority Issue #2 – Water Quality***

The water quality of Ithaca Reservoir and Cayuga Lake will continue to be a high priority. However, discrete stabilization "patches" are not likely to prove successful. A management strategy will be necessary to actively deal with sediment loads in the siltation pond and possibly with other detention/settling mechanisms at particularly problematic points within the watershed. In the long run, expenditure of resources on sediment management (i.e. collection and dredging) is likely to produce higher water quality in both Ithaca Reservoir and in Cayuga Lake as compared to spot fixes of streambank erosion.

The City of Ithaca has constructed and operates a large impoundment just upstream of Burns Road to trap sediment prior to its reaching Ithaca Reservoir. During two inspections of this area, the basins were observed to be discharging water that was more turbid than its inflow. This could be due to either high flows that resuspend and transport previous sediment deposits, in-basin algae blooms in nutrient rich water, or sediment laden runoff from adjacent processing and screening of previously dredged spoil material.

The efficiency of this basin could be improved in order to further help reduce sediment loads at the downstream reservoir. Specific recommendations are:

- Construct a forebay at the basins inflow point to trap coarse sediment in an area that can be accessed for annually cleaning.

- Add a series of internal groins or dikes to minimize resuspension of previous sediment deposits, and to avoid having direct through flows.

- Install a seasonal floating boom to trap surface debris and to support a turbidity curtain.

- Evaluate the frequency and magnitude of algae blooms to determine whether biological controls are warranted.

6.3 *Priority Issue #3 – Need for Coordinated Planning Efforts*

The increased industrialization and urban growth after the Civil War was followed in this century by the rapid growth of suburbs dependent on automobile transportation. Urban and suburban areas both increase the area of impervious surfaces and use artificial drainage systems to collect runoff. The prevailing philosophy for 100 years, which only recently began to change, was to convey the runoff to rivers as rapidly as possible. This reduces infiltration and evapotranspiration, increasing the volume of runoff and raising peak flow rates in the rivers.

In addition to raising peak flows, urbanization reduces the base flows necessary for aquatic life, recreation, and water supply in dry weather. The percentage of a watershed that is covered with impervious surfaces is one of the key parameters affecting urban runoff. Increased runoff into a river's channel and floodplain affect the river's hydraulics, altering its flow depth, velocities, flood frequency, scour, and sediments. Channel and floodplain encroachments, such as fill material, buildings, bridges, and culverts, can also reduce flow capacity of a river and increase peak flow rates and velocities.

The hydrologic effects of land use changes affect the shape, size, and form of stream channels. The higher flow velocities and more frequent floods scour the channel, enlarging the flow area. Unless lateral erosion is contained by soil and vegetative conditions, urban rivers will generally erode their banks and increase in width. Lateral erosion leads to steeper, less stable banks that tend to be undercut and then collapse into the channel, adding more sediment directly to the river. Urban streams are also known to erode their channel beds, causing degradation, especially in uniform soils, such as silts and clays.

Land use can have a marked impact on stream water quality, temperatures, and sedimentation and erosion. With increased impervious surfaces come higher peak rates of stormwater runoff, greater transport of contaminants, higher stream velocities, and often degraded water quality due to increased temperatures and an influx of pollutants. Generally speaking, water quality impacts begin to occur above 10% impervious area coverage in a watershed, wherein the most sensitive stream elements are lost from the system. Above 25%, water quality is often impaired, where most indicators of stream quality consistently shift to a poor condition, including diminished aquatic diversity, water quality, and habitat scores.

Detailed studies of numerous watersheds have shown that the physical, biological, and chemical (water conditions) usually deteriorate as the watershed becomes developed. The percentage of the watershed covered with impervious material such as rooftops, parking lots, roadways, and driveways is often used as an indication of urbanization. Research has demonstrated the following relationships between watersheds impervious cover and the streams condition. (Center for Watershed Protection, 1998) This information provides an initial method to rapidly assess watersheds susceptible to change.

TABLE 6-2
Relationship of Imperviousness to Water Quality

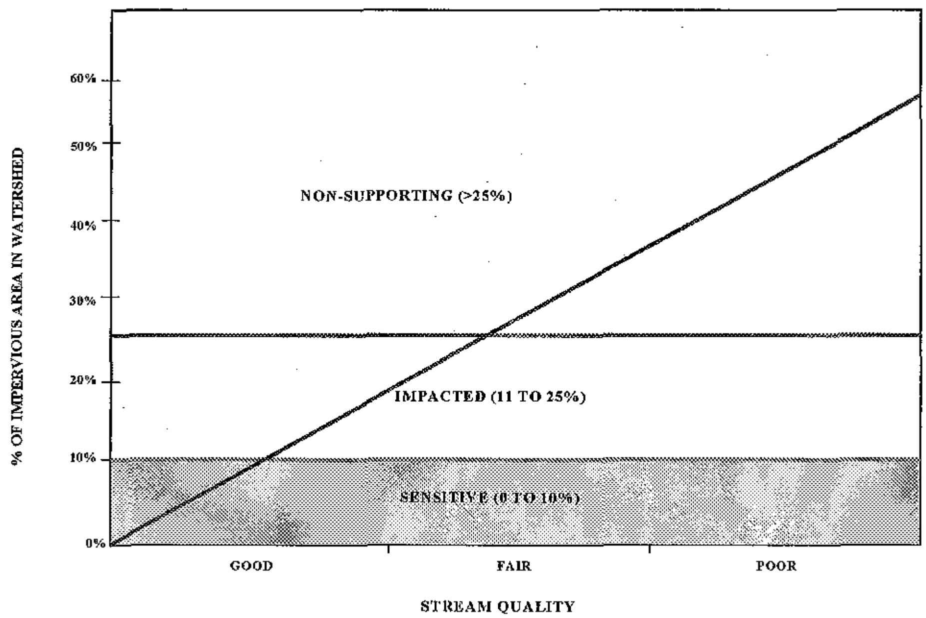
Watershed Impervious Cover	*Stream Quality*
0-10%	Good
10-25%	Fair, probable impacts
7-25%	Low, significant impacts

Streams with 10 to 25 percent impervious cover usually are impacted with erosion channel deterioration, unstable banks, reduced habitat, reduced biodiversity, and declining water quality. Streams within watersheds of over 25 percent impervious cover tend to be flood prone, highly unstable, with poor water quality and limited aquatic life. Figure 6-1 illustrates the relationship between impervious cover and stream quality, information that can be used to categorize streams as sensitive, impacted, or non-supporting.

The water quality of the sub-watersheds within Six Mile Creek as observed in the field and indirectly assessed using the impervious cover metric, is generally quite good. The only sub-area with high impervious cover and extensive storm drainage is WS-10, and to a lesser extent WS-20 and 30. Consequently, except in the City of Ithaca, watershed urbanization is not a significant factor in the health of Six Mile Creek.

However, future land uses and development practices and trends have the potential to have a marked negative impact on Six Mile Creek and its contributing tributaries. If unchecked, land use development could have profound and unwanted impacts. Zoning and wetlands regulations at the local level are not consistent within the County and, in some instances, are non-existent. Where they are in place, these regulations do not provide adequate controls for the maintenance of riparian buffers or protection against increases in peak stormwater runoff rate and/or volume that is generated by the creation of impervious surfaces (i.e. parking areas, buildings, sidewalks, etc.).

FIGURE 6-1
Relationship of Imperviousness to Water Quality



Source: Schueler & Claytor, 1996 ASCE

Development of a consortium or task force among the local Six Mile Creek member towns is strongly encouraged, wherein the framework can be developed for a watershed approach to future land use planning and reasonable controls. Of particular concern would be mechanisms to protect the hydrology and water quality within the watershed and to develop a riparian corridor within which development would not occur. Controls on encroachment will serve to protect the stream corridor as well as future structures.

6.4 *Past and Ongoing Management Measures*

All of the management measures that were inspected by MMI in Six Mile Creek consisted of channel stabilization projects or channel modifications. Several problem areas being considered for management due to bank or bed erosion were also inspected. Several of these, such as the Karig (Segment 3), Whitham (Segment 4), Tutton (Segment

8), Barille (Segment 8), and Moesch (Segment 8) properties, were referenced in the stream segment assessments.

Additionally, conventional stone riprap on graded stream banks were observed at several sites, including north of German Cross Road, south of German Cross Road, and at the gas pipeline crossing downstream of Banks Road. At all three sites, the riprap bank protection was effective in terms of resisting erosion. However none of the observed rip rapped areas has any vegetative cover and the exposed hot banks offer poor habitat.

Several bridges over Six Mile Creek have abutments and or wingwalls composed of vertically driven steel sheeting. This is a rapid and cost effective method of supporting bridge superstructures where deep or scour prone soils exist. The use of concrete pile caps or tie backs are common practice for this type of construction, but could not be visually verified. The vertical steel abutments can provide good scour protection if they are deep enough. However, these do not concentrate low flows and lack floodplain linkages.

While the areas targeted for restoration within Six Mile Creek focus on the upstream reaches that largely drive sediment loading and water quality, many of the remaining reaches, including the channelized segment in the lower watershed, can also benefit from restoration efforts. Of particular interest would be improving the ecological and recreational function of the lower watershed by acquiring a riparian zone along the channel. Concrete walls could be replaced with natural sloped banks. This would improve habitat function as well as public access opportunities.

7.0 *Existing Conditions – Salmon Creek*

7.1 *Background*

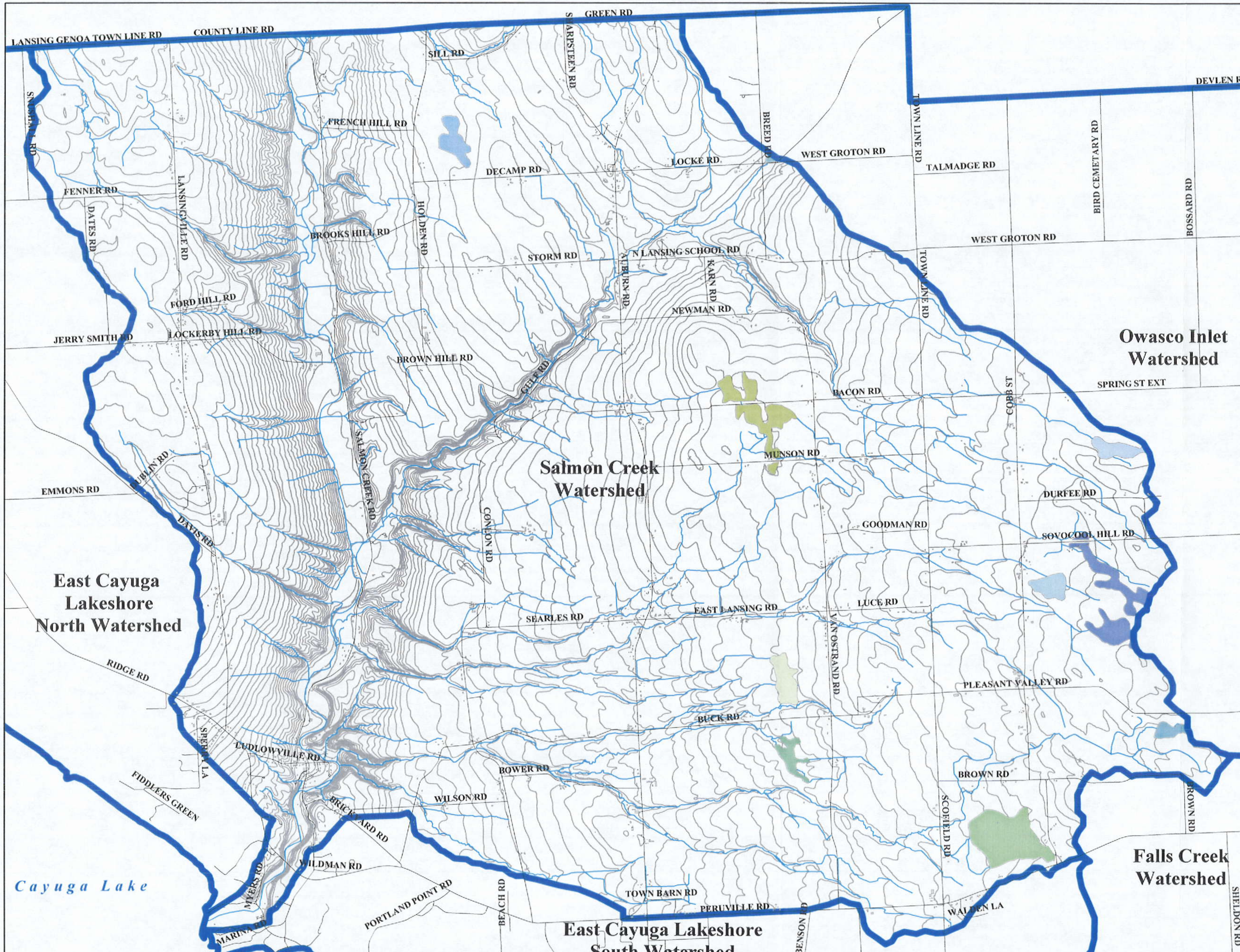
The Salmon Creek watershed spans 34 square miles within Tompkins County. Its headwaters are in Cayuga County and it discharges to Cayuga Lake. Salmon Creek flows from north to south into Tompkins County in the Town of Lansing. The creek is located in a straight incised valley that lies approximately 400 feet below the surrounding uplands, which have extensive agricultural land uses. Salmon Creek ultimately passes through the hamlet of Ludlowville and discharges into Cayuga Lake. Figure 7-1 is a location plan of the Salmon Creek watershed.

7.2 *Terrain*

The Salmon Creek watershed is dominated by high plateaus at elevation 900 to 1100, with mild surface slopes. This plateau is bisected by the pre-glacial incised valley of Salmon Creek and its principal tributary, Locke Creek, also known as "the Gulf". Salmon Creek flows generally south, following what appears to be a pre-glacial valley. Interestingly, in the next watershed to the east, Owasco Inlet is on a parallel course, but flows north.

7.3 *Existing Land Uses within the Salmon Creek Watershed*

The Salmon Creek watershed is characterized by large dairy farms and fruit orchards, with a low population density. Agricultural activity is also found on the long, narrow, flat floodplains along Salmon Creek north of Ludlowville. There are several "named" cross road hamlets, as well as the large population center at Ludlowville that developed around the falls and its former water powered mills. Today, this watershed is beginning to see suburban growth.



Legend

Salmon Creek Watershed

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Salmon Creek Watershed Location Map

Flood Mitigation Needs Assessment

Date: September 2005

Scale: 1:40,000

Sheet: Figure 7-1

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7.4 *Water Quality*

The southern basin of Cayuga Lake is included on New York State's *Priority Water Bodies List*, primarily because of the prevalence of silt and sediment. Southern Cayuga Lake is also included on the 303(d) list of impaired water bodies requiring a watershed approach to restoration. Visual observations of Salmon Creek during field inspections revealed high turbidity and color. The most likely sources are the natural fine grain soils and extensive agricultural fields.

7.5 *Hydrology of Salmon Creek*

The U.S. Geological Survey has a stream gauge located on Salmon Creek at Ludlowville, with a watershed area of 81.7 square miles. Gauge 04234018 was only operated full time from October 1964 to September 1968, most of which was a drought period. The mean monthly flows were as follows:

TABLE 7-1
Historic Mean Monthly Flows – Salmon Creek
(1964 – 1968)

Month	*Mean Monthly Flow*
January	65.8 cfs
February	129.0 cfs
March	217.0 cfs
April	136.0 cfs
May	95.1 cfs
June	50.3 cfs
July	23.9 cfs
August	13.8 cfs
September	16.0 cfs
October	23.2 cfs
November	72.0 cfs
December	78.8 cfs

The U.S. Geological Survey also measured the annual peak flood flow rates for the same period, as well as recording the flood flow from the 1935 event. The peak flows are summarized in Table 7-2 below.

TABLE 7-2
Peak Flows – Salmon Creek
(1964 – 1968)

Year	*Peak Flow*
1935	1,320 cfs
1965	536 cfs
1966	1,940 cfs
1967	1,170 cfs
1968	1,870 cfs
1969	2,000 cfs
1971	1,100 cfs
1972	4,160 cfs

8.0 Watershed Needs Assessment – Salmon Creek

8.1 Overview of Field Investigations

Milone & MacBroom, Inc. project team members conducted several field investigations of Salmon Creek in 2004 and 2005. The initial watercourse inspection occurred in July 2004, during steady rain that resulted in a bankfull flood event. A subsequent inspection was conducted in December 2004 during low flow conditions; and a follow-up reconnaissance inspection was conducted in May of 2005. The field investigations targeted areas of previously identified problems as well as representative stream sections, natural and man-made control points (such as dams, natural falls, and reaches flowing over bedrock), and areas of extensive lateral migration.

8.2 Stream Profile and Control Points

No field survey or published data is available to define the stream profile of Salmon Creek. Elevational control for the most downstream segment (#4) is Cayuga Lake, with a normal water surface elevation of 382 feet. Proceeding upstream, the spectacular Ludlow Falls is a giant headcut and the bedrock there controls the elevation of the remaining upstream segments. The creek rises to elevation 500 upstream of the falls within segment #2; and rises to elevation 600 in segment #1 between Brooks Road and French Hill Road in Lansing.

8.3 Needs Assessment by Stream Segment

For analysis purposes, reach segments were defined along the length of Salmon Creek. These are summarized in Table 8-1.

TABLE 8-1
Summary of Stream Segment Designations – Salmon Creek

Segment	*Description of Geographic Limits*	*Description of Conditions*
1	County Line to Lockerby Hill Road	Sinuous, Moderate Gradient
2	Lockerby Hill Road to Salmon Creek Road Bridge	Straight, Low Gradient, Stable
3	Salmon Creek Road Bridge to Ludlowville Falls	Sinuous, Confined, Degrading
4	Ludlowville Falls to Cayuga Lake	Deep, Narrow, Incised Valley with Bedrock Control

8.3.1 Segment # 1 – County Line to Lockerby Hill Road

Salmon Creek enters Tompkins County at Salmon Creek Road near Townline Road. The single span bridge has steel sheeting wingwalls and is in good condition. However, it is much narrower than the adjacent floodplain, and bank erosion due to contraction and a bend is occurring. Moving downstream, the creek follows an incised valley whose flat floodplain is about ten to 15 times the channel width. Nevertheless, the sinuous river does run along the valley sides in places. The bankfull width is typically 80 feet, with a bankfull depth on the order of three feet, and a total bank height of six to eight feet.

Large corn fields are present on the flat terraces that flank the lower floodplains. The actual floodplains from the county line to the Lockerby Hill Road bridge are generally rich riparian wetlands. The channel typically has vegetated point bars and cut banks on the bends. The steeper valley sides are generally forested, with some shallow incision of tributaries. Moderate slope areas tend to be used for corn or hay.

8.3.2 Segment # 2 – Lockerby Hill Road to Salmon Creek Road Bridge

The Lockerby Hill Road bridge is a single simple span with steel I-beams on concrete abutments. It is in good condition. The upstream right bank riprap and downstream left bank concrete jacks attest to concern about scour. Observed velocities were on the order of two feet per second, with some local riffles and fast runs.

The local glacial till has a high silt content and little gravel. This, combined with the active open agricultural fields, contributes to the river's high turbidity and light brown color. The channel generally has a gravel bed, with cobbles in selected areas. The latter are of non-local metamorphic rock, obviously dropped off by glaciers. Active channel erosion and realignment is occurring beginning 2,000 feet south of the Lockerby Hill Road bridge. There are several scroll lines, natural levees, split flow around mid-channel bars, and local widening with an increase of slope.

The channel opposite Brown Hill Road hugs the right side of the valley and has an atypical width of 75 feet. The profile is a bit steeper, with fast runs and some rapids, with a gravel and cobble bed. The terrace is used for corn fields.

Locke Creek (the Gulf) has a width of 20 to 25 feet, shallow depth, and a steep gradient. It is a major source of coarse bed load to Salmon Creek. It has a long, narrow ravine, up to 100 feet deep, accessible by Gulf Road.

Salmon Creek is actively starting to meander and migrate parallel to Salmon Creek Road south of the Lockerby Hill Road bridge. The channel narrows to as little as 30 feet, with rapid flow. Two sinuous bends have developed, with new point bars, cut bank erosion, and downed trees that are forming a log jam. Farther south, several residences and modular homes appear to sit on the active flood prone area.

8.3.3 *<u>Segment # 3 – Salmon Creek Road Bridge to Ludlowville Falls</u>*

Salmon Creek Road crosses the channel at the start of this segment on a single span green steal truss bridge with a span of about 100 feet. Bedrock is visible near the concrete abutments. The upstream channel is wide and shallow, probably due to the bedrock control. The bridge is slightly perched, with its deck above the floodplain. Therefore, the approach roadway is paralleled by an old overgrown dike.

Salmon Creek widens downstream of the bridge and slows, resulting in less sediment transport and a large mid-channel gravel bar. About 600 feet downstream of the bridge, the channel strikes the left valley wall, creating a huge active erosion site. The exposed bluff is about 80 feet high by 400 feet long behind the Lansing Road Rod and Gun Club. Upstream of the bluff, a massive log jam has developed.

The channel downstream of such a dramatic bluff erosion site would normally be choked with the excessive sediment loads, creating bars and islands. However, the flow past the escarpment is already accelerating on a steeper gradient, leading to the crest of the even more spectacular Ludlowville Falls. This is a 150-foot wide by 60-foot high vertical drop. The falls occur where a giant headcut is located over erosion-resistant bedrock, which is underlain by softer rock.

8.3.4 ***Segment # 4 – Ludlowville Falls to Cayuga Lake***

The water tumbles into Salmon Creek's lower bedrock gorge, a slightly sinuous canyon up to 100 feet deep, leading 1.5 mile to Cayuga Lake. This gorge represents an area where the creek has already downcut to reflect the base level at the lake.

The mouth of Salmon Creek has formed a large delta of sediment, extending into the lake. This is known as Myers Point and is home to Lansing Park. The delta is extending approximately 1,800 feet into Cayuga Lake, which is 6,500 feet wide at this point, with a depth of 300 feet.

9.0 *Priority Issues and Recommendations – Salmon Creek*

Salmon Creek is a mature alluvial river with a defined floodplain in most areas. Its profile is generally stable, controlled by the elevation of Cayuga Lake at its confluence and by the massive bedrock at Ludlowville Falls. The creek is laterally confined in several areas and is actively eroding the valley sides in Segment 3 upstream of Ludlowville Falls.

Most of the lateral tributaries convey runoff from the flanking plateau areas down very steep valley walls to Salmon Creek. None of these tributaries have reached a stable graded slope and active incision of narrow steep sided ravines is common.

9.1 *Priority Issue #1 – Address Bank Erosion Upstream of the Falls*

The base at the high raw bank upstream of the falls should be stabilized with bio-technical materials, and stone deflectors constructed to deflect high velocity currents away from the bank. This area is experiencing severe erosion and is a significant source of sediment input. A massive log jam has formed upstream of the bluff and should be cleaned out.

9.2 *Priority Issue #2 – Avoid Further Tributary Degradation*

As in other Tompkins County watersheds, the recommended management strategy for Salmon Creek is to avoid further tributary degradation by:

→ Preserving vegetated buffers along all channels;
→ Preventing increases in direct runoff by limiting impervious cover, encouraging stormwater detention, and using infiltration systems where appropriate; and
→ Searching out and stabilizing the larger headcuts or knick points to control sediment.

The active channel evolution south of the Lockerby Hill Road bridge should be monitored. There is a potential for the growing midchannel sediment bars to deflect the river's alignment.

9.3 *Priority Issue #3 – Minimize Surface Erosion*

Surface erosion is evident in the uplands of the Salmon Creek watershed, primarily associated with agricultural areas with extensive open fields, dirt roads, and open ditches. Mitigation of these sources of erosion could be accomplished on a local level, working with and providing guidance, education, and incentive to the agricultural community. Formal requirements can also be adopted through watershed management plans and/or local land use regulations.

10.0 Existing Conditions – Fall Creek

10.1 Background

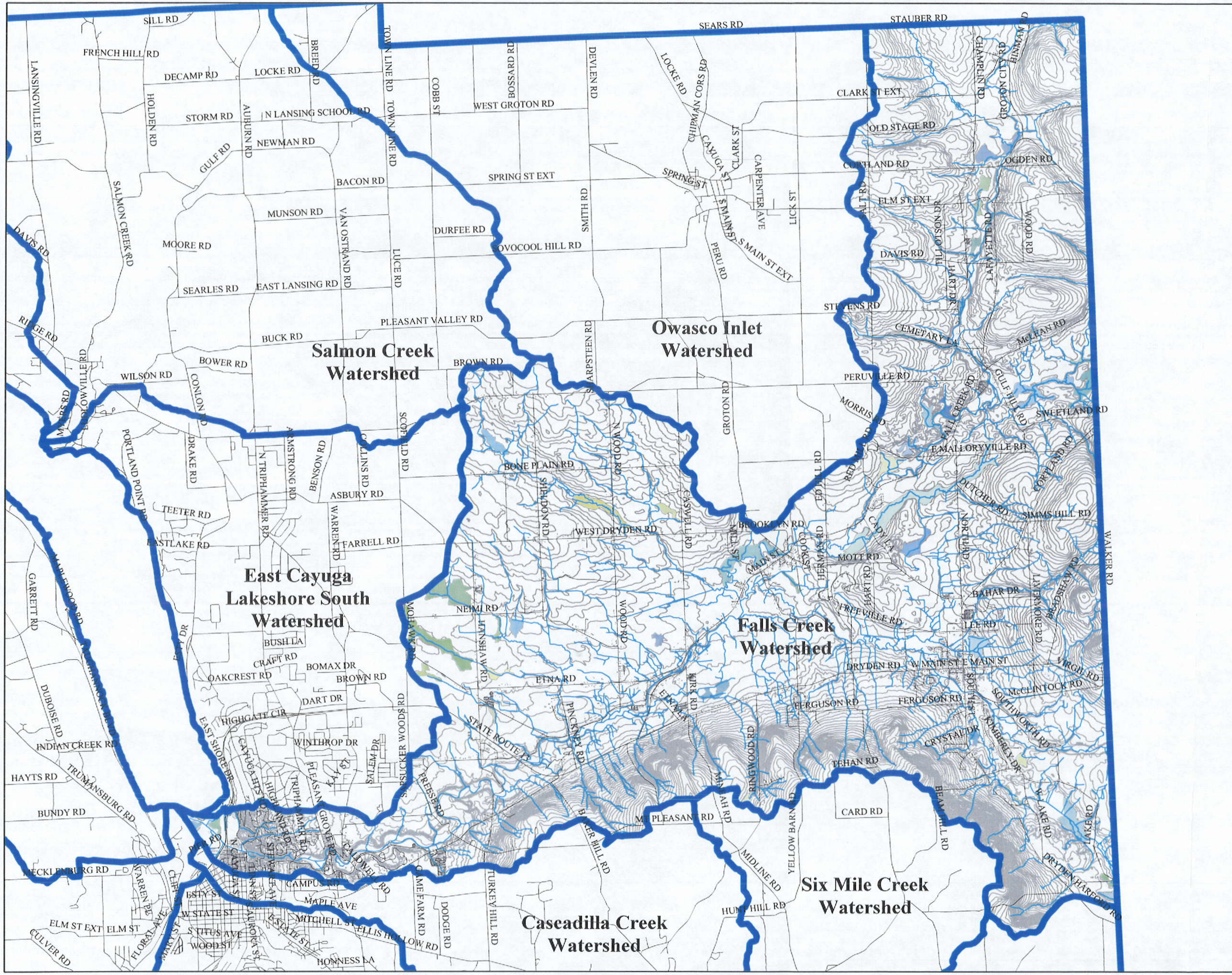
Fall Creek is a mid size watercourse with a drainage basin area of 126 square miles, extending from Cortland County along a southwesterly alignment to Cayuga Lake at Ithaca. It flows through the Towns of Groton, Dryden, and Ithaca. Figure 10-1 is a location plan of the Fall Creek watershed.

10.2 Terrain

Fall Creek watershed is characterized by high flat top hills that are remnants of the ancient Allegheny plateau with moderate to steep sides that drop to broad incised valleys. The valleys are generally underlain by shales and siltstones, while the hilltop and ridges are dominated by more erosion resistant sandstones intermixed with siltstones. Surficial soils consist of glacial till, except for outwash and lacustrive materials in the valleys.

10.3 Existing Land Uses within the Fall Creek Watershed

The Fall Creek watershed has a wide variety of land uses. Urban areas are found at the lower downstream end of the watershed on flat lands adjacent to Cayuga Lake, and at the Cornell University campus on the steep escarpment overlooking the lake. The western part of Dryden has mixed residential, retail, and commercial activities along the Route 13 and Route 366 corridors, in the hamlet of Etna, and the villages of Freeville and Dryden at the intersection of Routes 13 and 38. The majority of the watershed consists of active and inactive agricultural land in the valleys and lower gradient slopes, with forest land on the steeper slopes and hilltops. The Yellow Barn State Forest is located along portions of the ridge forming the south watershed boundary, separating Fall Creek from Six Mile Creek.



Legend

Fall Creek Watershed

Fall Creek Watershed Location Map

Flood Mitigation Needs Assessment

Date: September 2005	Sheet: Figure 10-1
Scale: 1:85,000	

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The watershed area north of the Etna area has gently rolling plateau land with a mixture of small farms, many abandoned fields, and increasing number of residences. Much of this area has a primary drainage system composed of roadside ditches, two to four feet wide, and one to four feet deep. The older ditches have natural grass and ground covers, often mowed, which stabilizes them well. However, some are eroding, and several recently cleaned ditches have raw erosion prone banks.

10.4 ***Water Quality***

The southern basin of Cayuga Lake is included on New York State's *Priority Water Bodies List*, primarily because of the prevalence of silt and sediment. Southern Cayuga Lake is also included on the 303(d) list of impaired water bodies requiring a watershed approach to restoration. Visual observation of Fall Creek during field inspections revealed high turbidity and color, as well as suspended sediments during higher flows. Water clarity during lower flows was clear and shallow.

10.5 ***A Review of Past Studies on Fall Creek***

There are numerous reports which provide helpful information on the Fall Creek watershed, ranging from state and county agency reports to academic studies prepared at Cornell University. Selected studies are summarized below:

→ The U. S. Department of Agriculture (1969) evaluated flood control needs along Virgil Creek, a major Fall Creek tributary, and eventually constructed a flood control impoundment along Egypt Creek upstream of Dryden Village. This report contains limited data on local geology, hydrology, and flood hazards.

→ Von Engeln (1961) provides an outstanding description of the regions recent glacial and post glacial history with numerous referenced to Fall Creek and the formation of the Finger Lakes. He describes the watershed as being a cuesta drainage pattern where the bedrock dips gently to the south, forcing Fall Creek to move laterally against the Mount Pleasant and Turkey Hill escarpment.

→ A detailed description of the watershed's natural resources, including soils, vegetation, wildlife, fisheries, land use, and economy is provided by Hamilton and Smith (1974). It was interesting to note that several of their land use predictions, made 30 years ago, have actually occurred. Specifically, the abandonment of marginal farm land and consolidation of larger farm units.

10.6 Hydrology of Fall Creek

The Federal Emergency Management Agency (FEMA) has prepared a Flood Insurance Study for the City of Ithaca. FEMA flood insurance studies are more in depth than the more generalized FEMA mapping. The study includes the lower reaches of Fall Creek. Predicted peak flow data is summarized in Table 10-1 below. No other communities within the Fall Creek basin have flood insurance studies.

TABLE 10-1
Peak Discharges in Fall Creek

Location	*Drainage Area*	*Peak Discharges*			
		10-Year	*50-Year*	*100-Year*	*500-Year*
Fall Creek Outlet	126 sq. mi.	5,920 cfs	8,950 cfs	10,430 cfs	14,400 cfs

Fall Creek stream flows are recorded at a long-term U.S. Geologic Survey flow gauge located at Forest Home along the edge of the Cornell Campus. The watershed at this gauge is comprised of 126 square miles. This area represents almost the full Fall Creek watershed. The gauged record extends from 1927 to the present. The mean monthly discharges are noted in Table 10-2 below.

TABLE 10-2
Mean Monthly Discharges in Fall Creek
(1927 to present)

Month	*Discharge*
January	191 cfs
February	220 cfs
March	410 cfs
April	410 cfs
May	212 cfs
June	122 cfs
July	72.4 cfs
August	51.2 cfs
September	64.5 cfs
October	101 cfs
November	175 cfs
December	205 cfs

The annual peak flows in this watershed are remarkably uniform, with all but three events being between 1,000 and 6,000 cfs. The maximum flood of record was 15,500 cfs in July of 1935, with a unit discharge of 123 cfs per square mile. The latter is virtually the same as the peak unit flood on Cayuga Inlet. The dominant discharge is estimated to be 4,000 cfs. The graphical plot of peak flow versus time does not show any obvious trends or changes.

11.0 *Watershed Needs Assessment – Fall Creek*

11.1 *Overview of Field Investigations*

Milone & MacBroom, Inc. project team members conducted several field investigations of Fall Creek in 2004 and 2005. The initial watercourse inspection occurred in July 2004, during steady rain that resulted in a bankfull flood event. A subsequent inspection was conducted in December 2004 during low flow conditions; and a follow-up reconnaissance inspection was conducted in May of 2005.

The field investigations targeted areas of previously identified problems as well as representative stream sections, natural and man-made control points (such as dams, natural falls, and reaches flowing over bedrock), and areas of extensive lateral migration.

11.2 *Needs Assessment by Stream Segment*

For analysis purposes, reach segments were defined along the length of Fall Creek. These are summarized in Table 11-1.

TABLE 11-1
Summary of Stream Segment Designations – Fall Creek

Segment	*Description of Geographic Limits*	*Description of Conditions*
1	Summer Hill	Mild gradient, , stable alluvial channel
2	Cayuga County Line to Route 222	Broad alluvial floodplain, meandering channel
3	Route 222 to McLean	Narrow floodplain, slightly sinuous, moderate gradient
4	McLean to Virgil Creek	Highly sinuous, alluvial channel with active meanders
5	Virgil Creek to Pinckney Road Bridge	Low sinuosity, increased gradient, coarse bed load
6	Pinckney road Bridge to Cornell	Entrenched meandering channel
7	Cornell to Ithaca Falls	Deep bedrock gorge with headcuts
8	Ithaca Falls to Cayuga Lake	Urban channel, flat gradient

11.2.1 Segment # 1 – Summer Hill

The first segment of Fall Creek is located in the Town of Summer Hill in Cayuga County, flowing south to Tompkins County. The high level channel above elevation 1,300 feet, traverses mild gradient farm land to the Groton town line. The alluvial channel is stable, but with high turbidity.

11.2.2 Segment # 2 – Cayuga County Line to Route 222

The creek's second segment is located fully within the Town of Groton, from the Cayuga County line to Route 222 at Lafayette Corners. This segment is only two miles long but is distinctive due to its broad alluvial floodplain and lack of lateral channel constraints. The gradient is about 10 feet per mile and the meandering channel is a Rosgen type C4 with active pasture and cornfields on both sides. At the single lane, steel truss bridge at Hinman Road, the channel's bankfull width is 15 feet and stable. The channel meanders at the large farms along Old Stage Road are also stable, as the channel widens towards 30 feet.

Approaching Route 222, Fall Creek enters a low gradient wetland system where egrets were observed. Turbidity increases below the confluence of Webster Brook.

11.2.3 Segment # 3 – Route 222 to McLean

Segment 3 extends from the Route 222 modern twin span bridge due south to the small nineteenth century village of McClean near the town line between Groton and Dryden. This 2.5 mile long channel is roughly parallel to Lafayette Road with a much narrower floodplain than segment 2. The slightly sinuous moderate gradient channel is laterally confined is several places as it abuts the valley walls at the floodplain edge.

The narrower floodplain limits agricultural activity, allowing for more woodland. During inspection, the Cemetery Lane bridge was closed, and the Champlin Road bridge was being repaired. The former has a steel truss on concrete abutments, with a single 40 foot span. The low vegetated banks are only three feet high. Typical channel bankfull widths are 25 to 35 feet with shallow flow depths and a gravel bed.

11.2.4 Segment # 4 – McLean to Virgil Creek

Leaving McClean, Fall Creek changes direction at the confluence of the much smaller Beaver Creek and flows to the southwest. Fall Creek is suddenly highly sinuous active confined meanders to Malloryville Road, then has active unconfined meanders and a broad floodplain to and past Freeville to the confluence of Virgil Creek. The irregular glacial Rome terrain from McClean to Malloyville provides an abundant volume of coarse grain sand and gravel bed load to the river. Fall Creek has an alluvial Rosgen type C4 channel through this segment, with sand and gravel bed. The steep near vertical low banks are cohesive silt and clay, possibly an old glacial lake bed. Some new floodplain filling was observed along Creek Road.

The Beaver Creek channel is of interest as it already has a southwesterly alignment prior to its Fall Creek confluence, so one could say it is the smaller but dominant pathway. Flooding has been reported at the Red Mills bridge area, where single family homes are on the low floodplain. They cannot be economically protected so they should ultimately be relocated or demolished upon obsolescence. Floodplain zoning would be an effective land use tool to minimize human and financial risks of this type. The narrow truss bridge is itself perched above the floodplain.

Cornell University has experimental farms along Creek Road at Herman Road, where Fall Creek has unusually active meanders. During the first inspection, in pouring rain, the creek was flowing bankfull in this reach with some overtopping. Subsequent inspections showed minor bank erosion with little lateral movement and no point bars. In conclusion, this reach is active but in equilibrium so no intervention is recommended. The current width of 30 feet is stable.

Fall Creek grows to a bankfull width of 35 feet approaching the Village of Freeville at Route 38. Two old abandoned railroad bridges over Fall Creek, just upstream of Freeville, have caught and accumulated debris that is a flood hazard. The bridges have six and 11 spans, respectfully, with a dense pattern of wood pile piers. The river bed is composed of sand and gravel.

The final channel reach of segment 4 extends from Freeville through a marshy area to the confluence of Virgil Creek at route 366. The channel is highly sinuous with silty cohesive banks, a Rosgen C5 channel type. The Route 38 bridge in Freeville has a 35-foot span and is in good condition.

11.2.5 Segment # 5 – Virgil Creek to Pinckney Road Bridge

The character of Fall Creek changes dramatically at Virgil Creek, from the upstream sinuous alignment with little bed load to the downstream channel with less sinuous alignment with little bed load to the downstream channel with less sinuosity and a higher coarse bed load with numerous bars and islands. The 3.5 mile long segment extends to Pinckney Road bridge. This segment has an increased gradient, bank erosion, and point bars with a hint of incision. The gross slope is about 15 feet per mile. The channel has a mean width of 40 feet, becoming somewhat wider at the bends.

The riverbed is generally composed gravel and cobbles up to four inches in diameter. The bridge across Fall Creek at Etna has a two lane wide steel deck, over a sandy bed. The adjacent floodplain is being filled opposite the Mills Apartments.

This segment receives significant sediment loads from a series of first and second order tributaries entering the left side of the channel from Mount Pleasant (see section 11.5.2), plus from the farm lands to the north (see section 11.5.1). These confluence bars push Fall Creek's channel towards the opposite banks, creating a locally sinuous thalweg.

11.2.6 Segment # 6 – Pinckney Road Bridge to Cornell

The Fall Creek segment from Pinckney Road to the Village of Forest Home at the edge of the Cornell campus is a classic example of an entrenched meandering channel that has eroded through to its bedrock control level. The first reach to the Route 13 bridge and canoe launch has 40-foot deep incised floodplains and a sinuous course, similar to a Schumm Stage V evolution stage. Several active point bars with chutes are present. Local erosion is occurring on some banks, particularly at the bends. However, there is little sediment accumulation as the steepening channel gradient provides normal velocities of 1.3 feet per second high transport capacity.

The bankfull channel width is typically 60 feet. Continuing downstream, the floodplain and meander belt widths increase to 600 feet with 100 feet of incision below surrounding plains. Barren valley banks up to 75 feet high at 45 degree slopes are present, composed of a very dense stoneless basil till. Several giant escarpments, both "dry" and "wet," attest to the rivers changing course on both sides of Varna, a flat bedrock channel invert is visible near the Cornell filter plant inlet dam, forming a grade control at the segments downstream end.

The Cornell Dam is a concrete ogee shaped concrete weir about eight feet high by 100 feet long, operated as a run of the river structure. The Freese Road bridge is a long twin span structure, one span is over the wet channel while the other is over a dry floodway. The riverbed is composed of cobbles and boulders with a fast run.

11.2.7 *Segment # 7 – Cornell to Ithaca Falls*

The Cornell University segment extends from Forest Home to Lake Street, at the bottom of Ithaca Falls. This segment is in a deep bedrock gorge with several headcuts including the spectacular Ithaca Falls and cascades above Beebe Lake. This small lake is a manmade impoundment within the gorge and is largely filled with sediment. The bedrock gorge with its entrenched meanders represents the transition from the Cayuga Lake plain at elevation 400 to the uplands channel at Varna. The riverbed rises about 450 feet in a distance of only 1.5 miles.

11.2.8 *Segment # 8 – Ithaca Falls to Cayuga Lake*

The final segment of Fall Creek extends from the gorges outlet near Ithaca Falls across a flat delta deposit to Cayuga Lake. The delta is an urban area of Ithaca.

11.3 *Virgil Creek*

The largest tributary to Fall Creek is Virgil Creek, with a confluence just below Freeville. Virgil Creek serves the southeastern part of the Fall Creek basin. The north and western part of the subbasin has large farms with pasture and row crops on moderate slope hillsides and low floodplains. The Dryden business district at Route 13 and 38 is within this subbasin.

The most notable aspect of the Virgil Creek basin is its apparent high sediment yield and bed material of sand and gravel that was observed in the channel. Site inspections and the USGS topographic maps of the Dryden Quadrangle reveal a locally significant band of kame and kettle glacial outwash deposits that appear to be the sediment source found between Virgil Creek and Route 13 and including the Dryden Lake area. The latter waterbody is 0.4 by 0.8 miles in size and appears to have shallow eutrophic waters. A park and New York state fishway access area is present, with signs indicating the lake supports large mouth bass, yellow perch, bluegills, suckers, and heron.

The new (1998) NRCS flood control dam on the upper part of Virgil Creek is an earth embankment with 4 60-inch diameter culverts serving as its primary spillway outlet. The low level pipes at the base of the dam allow normal flows to pass straight through, only impounding flood water. There is no conservation pool.

In view of the high sediment loads in Fall Creek and specifically Virgil Creek, it would be desirable to modify the outlet structure or approach channel to retain more sediment. Possible methods include:

→ Provide an outlet riser to form a temporary or permanent pool
→ Construct a north/south oriented filter berm across valley/pool area
→ Excavate a sediment basin upstream of the dam

A channel stabilization project was observed under construction along Virgil Creek parallel to East Lake Road. The intent is to prevent erosion of a high bank that endangered the road. The 1,200 ± foot long project relocates the 20 to 30 foot wide, gravel bed channel using a curvilinear alignment based on natural design concepts. It then uses conventional large stone riprap for bank stabilization rather than a fully naturalistic approach.

Portions of Virgil Creek have been previously channelized between Route 38 and Route 13 in the center of Dryden. This 40-foot wide by four-foot deep trapezoidal channel has low banks and a coarse gravel bed in good condition.

11.4 *Other Fall Creek Tributaries*

Numerous small streams discharge into Fall Creek in addition to the previously mentioned Virgil Creek. These tributaries fall into three main clusters. The northern upstream third of the Fall creek watershed is relatively narrow from McLean to the county line. As a result, the tributaries are relatively short with small subwatersheds on the uplands. The streams are generally first or second order and appear to be intermittent, primarily draining across disturbed agricultural land.

The northwestern part of the Fall Creek watershed, generally north of Etna and Varna, has extensive low gradient farm land draining south and southeast to Fall Creek. This region has extensive agricultural activity and some newer residential subdivisions. The street network is laid out with a grid of roads running east and west, crossed by roads running north and south with few topographic controls.

Most roads have well defined drainage ditches along both sides, intercepting both surface and ground water. The grid system of road ditches has captured much of the basin's runoff and effectively supplants the native first order collection streams.

The gentle south draining uplands appear to reflect the southerly strike and dip of the underlying bedrock. Bedrock is occasionally visible in the channel beds, such as Mill Creek at Farrell Road. Ditch erosion is quite common and recently maintained (dredged) ditches have raw unvegetated banks. Examples of eroding ditches include sections along Bone Plain Road, and Caswell Road.

The stream crossing at the intersection of Etna Road with Pinckney Road is an example of local degradation. The 12-foot wide channel has a typical flow depth of 0.5 feet with stable vegetated banks. The Etna Road culvert has twin 10-foot wide by six feet high corrugated metal pipe arches with old concrete end slope protection. The downstream channel has eroded three feet below the pipe invert, creating a "perched" outlet that blocks fish passage. The upstream channel is flush with the pipe invert, indicating the pipes have halted headcutting. Similarly, Mill Creek at Coswell Road has degraded downstream of the twin seven-foot culverts, but is stable upstream is on bare bedrock at West Dryden Road.

The southern part of the Fall Creek watershed drains the steep north facing side of Mount Pleasant. This region has a large number of closely spaced first and second order streams flowing north, across Routes 13 and 366, into the left side of Fall Creek. The streams in this area flow parallel to Baker Road, Midline Road, and Pine Woods Road, and have mean bed gradients of 15 percent, reducing to four percent grades on the valley bottoms from Route 13 to Fall Creek.

The small tributary stream (reach 21983055) parallel to Ringwood Road is a good example of the channel incision occurring on the steep slopes along the watersheds southern area. This stream has a normal base width of about six feet and flow depth of 0.5 feet. Its channel, however, is up to 30 feet wide with near vertical raw banks up to 10 feet high. The steep channel slope and limited coarse material in the till soil allows it to erode without limit until bedrock is reached.

The slope and estimated flood flow depth of two feet creates a shear stress that is sufficient to initiate motion and erode rocks, and there are insufficient rocks of this size to cover the bed.

12.0 Priority Issues and Recommendations – Fall Creek

12.1 Priority Issue # 1 – Floodplain Management

Numerous sites within the Fall Creek watershed were observed to have recent fill material on active floodplains, other areas had residential development in flood prone areas. In order to reduce flood hazards, and preclude future incremental flood risks, communities could adopt floodplain management regulations.

Site inspections found that active construction sites in the basin generally do not include use of soil erosion and sediment control measures. Adherence to the New York Soil Erosion Control Manual should be pursued through local land use regulations.

Many river reaches have active agricultural activities near the channel with little or no vegetated buffer zones. Establishment and maintenance of vegetated buffer zones will reduce sediment and nutrient levels, and provide habitat.

Finally, unvegetated roadside ditches contribute to the overall sediment loading in Fall Creek. These should be stabilized with vegetation and periodically maintained.

12.2 Priority Issue #2 – Abandoned and Undersized Bridges

The two abandoned timber supported railroad bridges over Fall Creek, just upstream of Freeville, should be removed. With few exceptions, the roadway bridges over Fall Creek seldom span more than the bankfull channel width and are far too small. This increases flood hazards and channel erosion. Flow capacity at actively used bridges should be further evaluated and undersized bridges should be replaced.

12.3 *Priority Issue #3 – Eroding Tributaries*

The north flowing tributaries on the Mount Pleasant and Turkey Hill Ridge have locally extreme active erosion of bed and banks, providing high sediment loads to Fall Creek. A subsequent detailed inspection of each tributary is recommended, followed by corrective control measures. Also, the high exposed river banks west of Route 13 bridge near Varna should be monitored in view of their erosion potential. Biotechnical bank protection should be considered.

12.4 *Priority Issue #4 – Modification of Flood Control Dam*

The NRCS dry flood control dam in the Virgil Creek watershed should be modified to trap sediment.

12.5 *Priority Issue #5 – Consideration of Future Water Supply Sources*

Coarse grain kame and kettle terrain north of Malloryville and southeast of Dryden are expected to have excellent ground water recharge capacity and should be considered for future water supply usage.

12.6 *Priority Issue #6 – Channel Restoration Monitoring*

The recent channel restoration project on Virgil Creek near East Lake Road is a hybrid approach to erosion control. This site should be monitored to assess its performance and potential application elsewhere.

12.7 *Priority Issue #7 – Turbidity Monitoring*

Fall Creek waters were observed to have high turbidity. In order to identify source areas, it is recommended that TSS and turbidity be monitored during both dry and wet weather.

12.8 *Priority Issue #8 – Public Access and Educational Opportunities*

There is limited public access to the river, despite its high potential for canoe and recreational fishing. Increased public access would be desirable. The wide variety of channel patterns, entrenchment, bedrock controls, and headcuts make Fall Creek an excellent site for educational and river research purposes.

13.0 Existing Conditions – Cayuga Inlet

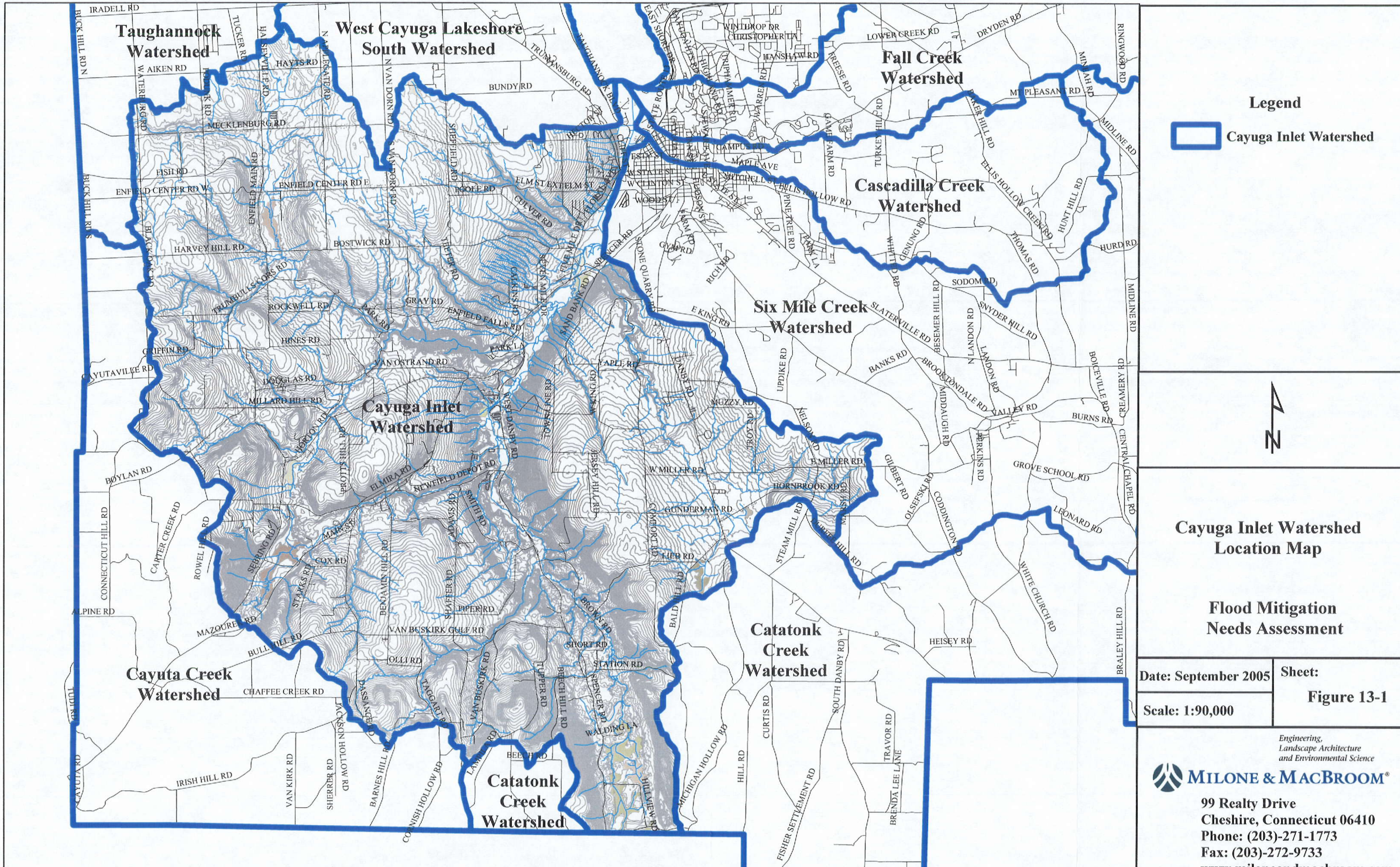
13.1 Background

The Cayuga Inlet watershed encompasses a 92 square mile area within Tompkins County, flowing from south to north along a glacial through-valley from the vicinity of the Spencer town line to Cayuga Lake at Ithaca. As a result of glaciation, the flow direction of Cayuga Inlet is to the north, as compared to the other southerly drainages in Tompkins County. Cayuga Inlet flows through the Towns of Newfield, and Ithaca, with tributary flow from Enfield and Danby. Figure 13-1 is a location map of the Cayuga Inlet watershed.

Cayuga Inlet is a special significance because its broad level delta at the end of Cayuga Lake provided favorable conditions for early settlement at Ithaca, and its linear valley provides easy transportation access to the Susquehanna region of north central Pennsylvania.

13.2 Terrain

The Cayuga Inlet drainage basin has a wide range of topographic and geologic conditions. The main channel follows the through-valley, with headwaters located on glacial moraine that creates a giant mound, splitting the valley drainage. In contrast, the major tributaries to Cayuga Inlet form on the adjacent highlands and then plunge down to the lower through-valley. Several tributaries, including Enfield Creek, Coy Glen, Van Buskin Gulf, and Buttermilk Creek have dramatic steep narrow ravines with waterfalls. The latter are concentrated in the lower reaches of the tributaries where knick points are receding upstream into sedimentary bedrock.



Cayuga Inlet Watershed Location Map

Flood Mitigation Needs Assessment

Date: September 2005	Sheet: Figure 13-1
Scale: 1:90,000	

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The base of the "U" shape Cayuga Inlet Valley is reportedly filled with hundreds of feet of alluvial sediments. This low lying area is prone to flooding and dynamic river processes.

13.3 Existing Land Uses within the Cayuga Inlet Watershed

The Cayuga Inlet watershed has a wide range of land uses and land covers that mirror its varied terrain. The upland areas of Newfield and Danby have active farmland across the broad hilltops and hill slopes, while mixed hardwood forests with some coniferous forest mantles the steeper valley slopes.

The broad flat valleys along the northern end of the basin have higher levels of development with residential and light industries. The outwash plains along Routes 34 and 13 in Ithaca have intense land use development with modern retail and commercial uses, as well as the largely residential areas of central Ithaca.

13.4 Water Quality

The southern basin of Cayuga Lake is included on New York State's *Priority Water Bodies List*, primarily because of the prevalence of silt and sediment. Southern Cayuga Lake is also included on the 303(d) list of impaired water bodies requiring a watershed approach to restoration. Visual observations of Cayuga Inlet during field inspections revealed high turbidity and color, as well as suspended bed load sediments during higher flows. The most likely sources are the natural fine grain lakebed soils, glacial moraine soils in the headwaters, and the coarse bed load from the steep incised tributaries.

13.5 Hydrology of Cayuga Inlet

Cayuga Inlet has a long history of flooding as it approaches Ithaca. An extensive flood control project with channelization, dikes, and large grade control structures extends roughly from the confluence of Buttermilk Creek near Spencer Road to the lake. This Corps of Engineers project reduces flood levels but is still prone to "backwater" from variable lake levels. The broad low gradient channel is prone to sediment deposition. The lake levels are partially regulated at its northern end by the Canal Corp.

The U.S. Geological Survey operates a long-term stream flow gauge on Cayuga Inlet near Ithaca at the Newfield town line. This gauge has a watershed area of 35.20 square miles and is at elevation 437 feet above mean sea level. It is located upstream of Buttermilk and Enfield Creeks, and therefore excludes data from these important tributaries. The period of record is from 1937 to the present. Table 13-1 presents historic mean monthly flows from this gauge station.

TABLE 13-1
Historic Mean Monthly Flows – Cayuga Inlet
(1937 – Present)

Month	*Mean Monthly Flow*
January	37.1 cfs
February	47.7 cfs
March	88.0 cfs
April	86.7 cfs
May	51.3 cfs
June	27.8 cfs
July	14.9 cfs
August	11.6 cfs
September	11.7 cfs
October	19.6 cfs
November	30.6 cfs
December	39.2 cfs
Mean	*38.9 cfs*

The mean monthly flows exhibit a typical seasonal flow pattern similar to other northeastern watersheds, with spring flows of 2.4 cubic feet per second per square mile (cfs/sm) and late summer flows of 0.33 cfs/sm. The peak flood of record is 6,500 cfs in 1935, amounting to a unit discharge of 186 cfs/sm, which is quite reasonable. In 68 years, only five peak annual floods have exceeded 4,000 cfs. The mean of the peak annual floods, which often correlates to channel forming discharge, is about 1,800 cfs.

The graphical plot of the peak annual floods in chronological order does not reveal any unusual patterns, leading to the conclusion that land use and channel conditions do not appear to be altering peak flows.

A FEMA Flood Insurance Study was prepared for Ithaca in 1981. It includes hydrology data for several rivers and detailed hydraulics for Cayuga Inlet, as well as maps of flood hazard areas. The peak flood flow rates for Cayuga Inlet are tabulated in Table 13-2 below.

TABLE 13-2
Cayuga Inlet Peak Flows

Location	*Drainage Area*	*Flood Frequency/Flow*			
		10	*50*	*100*	*500*
At Cayuga Lake	158 sq. mi.	8,600 cfs	14,650 cfs	17,710 cfs	26,300 cfs
Above Six Mile Creek	90.6 sq. mi.	5,650 cfs	9,600 cfs	11,600 cfs	17,250 cfs

14.0 Watershed Needs Assessment – Cayuga Inlet

14.1 Overview of Field Investigations

Milone & MacBroom, Inc. project team members conducted several field investigations of Cayuga Inlet in 2004 and 2005. The initial watercourse inspection occurred in July 2004, during steady rain that resulted in a bankfull flood event. A subsequent inspection was conducted in December 2004 during low flow conditions; and a follow-up reconnaissance inspection was conducted in May of 2005.

The field investigations targeted areas of previously identified problems as well as representative stream sections, natural and man-made control points (such as dams, natural falls, and reaches flowing over bedrock), and areas of extensive lateral migration.

14.2 Stream Profile and Control Points

Water levels and stream bed elevations in the downstream end of Cayuga Inlet are controlled by the base level of Cayuga Lake. The New York Department of Transportation controls the lake's outflow as a source of water for the New York State Barge Canal.

The headwaters of the Cayuga Inlet main stem are at approximate elevation 1,100 feet, flowing north for 12 miles to the lake at elevation 382. The mean gradient is a steep 60 feet per mile. The river inspection did not find any bedrock headcuts or control points along its fairly uniform profile, attributed to its position on glacial debris in the through-valley. In contrast, many tributaries are very steep with bedrock ravines and active waterfalls.

The flood insurance study for the City of Ithaca reports the following Cayuga Lake floodwater elevations:

TABLE 14-1
Flood Water Elevations in Cayuga Lake

Frequency, Years	*Lake Level*
10	384.8 feet
50	385.5 feet
100	386.3 feet
500	387.2 feet

14.3 Needs Assessment by Stream Segment

Cayuga Inlet has a wide variety of channel types and habitat due to its variable gradient and the combined flows and sediment loads from its tributaries. For analysis purposes, reach segments were defined along the length of Fall Creek. These are summarized in Table 14-2.

TABLE 14-2
Summary of Stream Segment Designations – Cayuga Inlet

Segment	*Description of Geographic Limits*	*Description of Conditions*
1	Spencer to West Danby	Broad through-valley
2	West Danby to Stratton	Entrenched, sinuous channel with small floodplain
3	Stratton to Newfield	Wider valley with coarse grain stratified drift
4	Newfield to North of Routes 13/34	Low gradient, sinuous channel with broad through-valley
5	Routes 13/34 to Cayuga Lake	Dredged flood control channel

14.3.1 Segment # 1 – Spencer to West Danby

This segment consists of the headwaters zone beginning near the county line at Spencer to West Danby. It is characterized by a broad through-valley with locally irregular terrain due to glacial moraine, forming the divide between the north flowing Cayuga Lake basin and the southerly flowing Susquehanna River basin. It is a region of small farms, and many ponds in scattered isolated depressions.

The channel flows through a series of very low gradient wetlands, some with open marsh, others with forested red maple dominated hardwood forest. No problems were noted in the limited accessible areas in this segment.

14.3.2 Segment # 2 – West Danby to Stratton

The channel from West Danby to Stratton at the confluence of Van Buskirk Gulf is still traversing the end moraine, but differs in that the channel is more entrenched and has the beginning of a small floodplain. It is similar to stage II of the Simon Channel Evolution Model. Occasional active channel and floodplain deepening and widening is producing varied habitat, but the channel width and discharge rates are still modest. This segment is a sediment source rather than deposition area. The channel is sinuous with frequent point bars, chutes, and lateral confinement.

14.3.3 Segment # 3 – Stratton to Newfield

The valley widens from Stratton to the Newfield town line and confluence with Enfield Creek, providing room for the highway, railroad, and moderate development along the river. River banks reveal coarse grain stratified drift along the banks with a mixture of rounded metamorphic rocks and the local flat shale fragments. Significant channel erosion is occurring near the intersection of Thomas Road and Route 34, and again at the high voltage power line crossing.

The channel base width has increased to 15 - 20 feet with a bankfull width of up to 75 feet. Bend erosion is occurring at numerous sites, such as upstream of Shelter Valley Road. The extensive trailer park homes in Newfield Station may be in flood hazard areas, although the railroad embankment helps to reinforce the bank area.

The Newfield Depot Road bridge cover Cayuga Inlet has a 25-foot wide by 10-foot high waterway. The concrete arch bridge has an unusual concrete slab that forms the river bed. This slab forms a barrier that blocks fish passage. Adjacent river banks have recent scour.

The Shelter Valley Road bridge crosses Cayuga Inlet with a single 30-foot span, with concrete deck and steel sheeting abutments. The 30-foot wide channel has moderate velocities, high turbidity, numerous loose logs, and moderate bank erosion.

This channel segment has reaches of both Rosgen type B3/4 plus other flatter reaches that are type C3/4. At several points, river bed degradation is just beginning to expose old glacial lakebed clays that are visible in the banks.

14.3.4 Segment # 4 – Newfield to North of Routes 13/34

Cayuga Inlet's channel from Enfield Creek to the start of the flood control project near the confluence of Buttermilk Creek is a low gradient sinuous Rosgen type C channel. It is located in a broad, flat bottomed glacial through-valley underlain by glacial lake bed clay sediments.

This channel segment receives high levels of coarse bed load sediments of gravel and cobbles from two major tributaries (Enfield Creek and Buttermilk Creek) plus several smaller channels that are incised into the valley walls. As a result, the river bed substrates are mainly gravel, with some sand and many cobbles. Numerous midchannel bars are present, indicating excessive sediment loads. The gravel and cobbles cover the minimizing bed erosion, however, the river is eroding the banks leading to higher sinuosity and many undermined trees. The channel's base width is typically about 50 feet with bankfull depths of four to five feet. The floodplain is active, with visual evidence of overbank flow, scour, debris, and old oxbows.

Severe channel bank erosion was found upstream of the Route 13 bridge, east of the railroad. The erosion is occurring on at least two large meander bends and connecting reach; it includes bend lateral migration, braiding, and many trees down. The banks are about six feet high and consist of vertical cohesive silt/clay. The channel is alluvial with a flat, flat plain.

This problem site is a significant sediment source very close to the channelized flood control project, and could eventually threaten the railroad. Log jams could induce more overbank flows and migration, or logs moving downstream could catch on bridges.

14.3.5 <u>Segment # 5 – North of Routes 13/34 to Cayuga Lake</u>

The downstream end of Cayuga Inlet, beginning one half mile north of Routes 13 and 34, extends for 2.5 miles to Cayuga Lake. This flat segment consists of a dredged flood control channel followed by a navigable channel with small boat marinas.

The broad floodplain between the channel and Route 13 appears to be the top of an old delta deposit that has filled the end of the lake. It is a heavily developed area with large retail stores (Kmart, Home Depot), fast food restaurants, auto sales dealerships, and industrial sites. The west bank along Route 13A is more residential.

Both channel reaches have water levels influenced by the lake and have low banks. Flood hazards probably exist during periods of high lake levels and high runoff. The low velocity channels will be prone to sediment deposition.

The flood channel south of State Street is a 200-foot wide trapezoidal cross section with 2:1 (horizontal to vertical) riprap banks up to eight feet high. Several public access points are available, but no full length trail. This channel has an 80-foot wide concrete grade control structure with an inoperable fish ladder. The water was a deep brown color with high suspended sediments. A dike extends from the railroad bridge to Route 13.

The navigable channel acts as an extension of the lake and receives runoff from Six Mile Creek and Cascadilla Creek in Ithaca.

14.4 Enfield Creek

Enfield Creek is the largest tributary of Cayuga Inlet. The river flows out of the Town of Enfield to the southeast, crossing into the Town of Ithaca within Robert H. Tremen State Park. The upper (northern) segment of Enfield Creek is a narrow Rosgen Type "C" alluvial channel only six feet wide, with a broad agricultural floodplain. Minor natural bank erosion is occurring upstream of Enfield Center Road. Much of the sediment is probably settling in the rich wet meadows leading to Bostwick Road.

The channel at Enfield Falls Road has increased in width up to 20 feet, with a shallow two-foot depth, and minor incision. The downstream side of the Hines Road bridge has two rows of steel sheeting driven into the river bed to serve as a headcut control. The channel at this point is about 25 feet wide, with a gravel and cobble bed. The incision increases rapidly downstream of Hines Road, finally entering the state park near the upper Park Road. Within the State Park, Enfield Creek flows within a steep-sided gorge known as "Enfield Glen." The channel at this point is up to 30 feet wide and six feet deep, with a cobble bed and moderate bank erosion.

The Enfield Creek gorge has been excavated since the last ice age, only in the past 11,000 years or so. In some areas, the creek has re-excavated an "inter-glacial" valley or gorge that existed before the last ice age. In other areas, the creek has become superposed on bedrock areas, causing excavation of a new gorge. As a result, some portions of the

Enfield Creek valley are wide with gradual side slopes of unconsolidated sediments, while other portions of the valley are characterized by the steep-sided gorge with bedrock walls.

Where Enfield Creek has excavated the interglacial gorge, glacial till has been eroded from the gorge. This till was deposited into the pre-existing gorge during the last ice age. In these interglacial gorge areas, soil creep and debris flows are evident in the hillside that is slumping down.

Where Enfield Creek has excavated a new gorge, Devonian bedrock has been eroded. Excavation of the new gorge is controlled by joints in the bedrock, with one joint set parallel to the flow and one set perpendicular to the flow. As a result, large rectangular blocks of shale and siltstone have eroded during flood events. Evidence of frost wedging is also visible in the gorge.

Waterfalls in Enfield Glen have migrated upstream over the last 11,000 years. As a result, hanging tributaries, potholes, chutes, and plunge pools are all present in the Glen. Abandoned plunge pools show that waterfalls have migrated upstream. Although Enfield Creek is actively eroding into glacial till (in inter-glacial gorges) and bedrock (in the recent gorge), the parts of the valley in glacial till cannot be excavated deeper or faster than the parts of the valley in bedrock. Thus, erosion of bedrock controls the pace of overall erosion along parts of Enfield Creek, and this may be seen as a natural method of slowing the erosion of sediment.

The channel downstream of the knick points and falls run across a flat outwash plain, with a bankfull width up to 50 feet and near vertical 10-foot high banks. The confluence delta into Cayuga Inlet appears to have pushed that channel to the east.

14.5 Coy Glen

The stream in Coy Glen has a relatively small watershed, beginning in eastern Enfield, and much smaller than the watershed above Enfield Glen. However, just like Enfield Creek, the stream in Coy Glen flows in a southeasterly direction, perpendicular to the Cayuga Inlet valley, and then joins Cayuga Inlet near the valley floor at the end of the flood control project. The watercourses drops an incredible 700 feet in only two miles.

Three hanging deltas are located along the creek in Coy Glen, representing ancient lake levels. Like Enfield Creek, Coy Glen's creek flows on a bedrock channel in many locations. Two joint sets in the bedrock locally control flow direction. Incised meanders in the bedrock are visible in several locations. In other locations, active undercutting of banks is apparent.

Potholes in the bedrock channel are an interesting record of activity in the watershed. These potholes were reportedly absent in the 1940s. Since that time, quarrying has occurred in the watershed, and it is thought that the potholes have formed due to additional sand in the stream, which is harder than the shale stream bed. At least eight potholes are present.

The sediment load and flood waters from Coy Glen discharge directly into the dredged Cayuga Inlet channel approaching Ithaca, without opportunity for storage or attenuation.

14.6 Buttermilk Creek

The highlands east of Cayuga Inlet are drained primarily by Buttermilk Creek. This watercourse flows roughly north by northwest parallel to Danby Road, then plunges into the through-valley at Buttermilk Falls State Park. Most of the subwatershed has relatively low relief on the glacial moraine of the hillcrests.

Buttermilk Creek begins at Jennings Pond, a shallow upland waterbody with extensive emergent aquatic vegetation. Its small park has a public beach. The creek extends northward through second growth hardwoods and former agricultural land, with a typical bankfull width of only 10 feet at West Miller Road. The channel then begins to become incised with an increasing gradient. The incised channel has created a gorge up to 50 feet deep at Comfort Road with a bedrock base. Much of the material removed from the gorge has settled in Lake Tremon, filling portions of the lake.

Buttermilk Falls are the incised knick point reach to the bottom of Cayuga Inlet Valley, with a combination of cascades cut into shale and sandstone.

A relatively large mass of loose coarse sediment has accumulated between the falls and highway bridge. This material consists largely of pieces of shale up to the size and shape of a dinner plate and fragments thereof. This appears to be fresh material derived from the extensive shale exposures in the Buttermilk gorge. Some of these modern deposits are re-eroding, as evident by vertical banks and bank slides.

Other tributaries along the east side of Cayuga Inlet are short and steep as they go down the overly steep valley walls. Many incised channels are located on the valley wall east of Route 34 and 96, providing a rich source of sediment to Cayuga Inlet.

14.7 Van Buskirk Gulf

Van Buskirk Gulf is a mid-size watercourse extending from the uplands in south Newfield in a northeasterly direction to Cayuga Inlet at Stratton. This channel is actively eroding into glacial till, indicating a post-glacial channel, only occasionally reaching bedrock. The gorge is increasingly deep (over 100 feet) downstream of Gulf Road, with numerous down trees and erosion in inaccessible areas. This long-term natural sediment load and its resulting delta appear to have pushed Cayuga Inlet to the east side of its valley.

15.0 Priority Issues and Recommendations – Cayuga Inlet

15.1 <u>Priority Issue # 1 – Sediment Sources</u>

Cayuga Inlet is receiving excess sediment from its headwaters, due to the erodible glacial moraine soils and steep tributaries, resulting in downstream deposition in the flood channel and lake. The steep tributaries, including Enfield Creek, Buttermilk Creek, and others, produce a large volume of coarse shale rock fragments that become bed load sediment. Cayuga Inlet north of the Newfield town line is in contact with fine grain lakebed sediments that create high turbidity.

The high quantity of bed load sediments found in Cayuga Inlet north of Enfield Creek has armored the bed, encouraging lateral erosion into the banks, and promoting increased meandering. This then produces fine grain sediments and a visible increase in turbidity. This is a natural process that is hard to prevent. The main stem channel has no significant sediment sinks prior to the flood control channel. It is the first depositional zone.

The channel widening and lateral migration immediately south of Routes 13 and 34 is a major sediment source that could be minimized. This area should be further monitored and evaluated prior to developing a specific plan. However, bank stabilization through application of bioengineering techniques, along with establishment of grade controls would seem appropriate here. Grade control is anticipated to prevent the reach of laterally migrating stream from expanding.

15.2 <u>Priority Issue # 2 – Address Bank and Bed Erosion at Select Locations</u>

Bank erosion has been identified at numerous discrete locations along Cayuga Inlet and its tributaries. Correction of these sediment input areas would be desirable. Additionally, the Cayuga Inlet main channel would benefit from the addition of anchor points to limit channel incision.

15.3 *Priority Issue #3 – Evaluate Fish Passage at Grade Controls*

Main channel fish passage is obstructed by the grade control structure and the Newfield Depot Road bridge invert. All major tributaries have fish passage blocks at waterfalls. As a result, aquatic habitat is fragmented and self-limited. These areas should be further evaluated to determine if physical modifications or construction of structural controls would be effective in providing for fish passage.

15.4 *Priority Issue #4 – Lack of Flood Insurance Studies*

There are no FEMA Flood Insurance Studies for Newfield or Danby, despite extensive flood prone areas and development that may be occurring in flood prone areas. Flood Insurance Studies should be prepared for the major watercourses in these communities. Several low-lying trailer parks are located along Cayuga Inlet in the Town of Newfield. It is unclear if they are in a flood hazard zone.

16.0 Summary and Implementation Strategy

16.1 Introduction

Throughout the Flood Mitigation Needs Assessment, Milone & MacBroom, Inc. has identified numerous problem areas consisting of channel distress along the watercourses or problems in their watersheds. Certain systematic patterns were found related to long-term geologic processes as well as small-scale local abnormalities.

Confined lateral migration is occurring where meandering channels have moved laterally into contact against high bluffs or terraces, causing impressive steep barren banks subject to spectacular but infrequent mass failures. This condition was identified in Salmon Creek at Ludlowville, in Fall Creek at Varna, and in Six Mile Creek at Six Hundred Road.

In contrast, unconfined lateral migration is occurring where channels are actually meandering on floodplains with low banks, creating frequent but small sediment pulses. This can be seen in Six Mile Creek, Cayuga Inlet, and Fall Creek.

Glacial terminal moraines with loose granular sediments (kame and kettle terrain) were identified in the headwaters of Cayuga Inlet and Virgil Creek. These were found to be major natural sediment sources. General degradation was observed at the headwaters of Cayuga Inlet, in Six Mile Creek, and at the gorges in Enfield and Buttermilk Creeks.

Evidence of surface erosion was less than expected and was associated with agricultural areas with extensive open fields, dirt roads, and open ditches, such is the case in the Salmon Creek uplands and in the central watershed of Fall Creek.

Several depositional areas have been identified where excess sediment accumulates and may be a nuisance, but which help to decrease the volume of material reaching Cayuga Lake. The periodic dredging of sediment from the impoundments listed in Table 16-1 would be expensive, but very effective in protecting the lake.

TABLE 16-1
Sediment Deposition Areas

Six Mile Creek	Reservoirs
Fall Creek	Beebe Lake
Virgil Creek	Dryden Lake
Buttermilk Creek	Lake Treman
Cayuga Inlet	Flood Control Channel

Table 16-2 identifies six types of erosion related watershed processes and provides a subjective rank of the problems' frequency or magnitude. The qualitative ranking is not based upon any type of quantitative or formal point system and could be subject to change during more detailed inventories; however, it provides an overview of issues in the streams and their watersheds.

TABLE 16-2
Channel Mechanics

Location	*Surface Erosion*	*Gully & Gorge*	*Channel Enlarge*	*Increased Sinuosity*	*Valley Widening*	*Lateral Migration*
Six Mile Creek	L	M	M	H	L	H
Salmon Creek	H	H	L	L	M	M
Gulf Creek	H	H	M	L	L	L
Upper Fall Creek	L	L	L	L	L	L
Lower Fall Creek	M	H	L	L	M	M
Virgil Creek	M	L	L	L	M	M
Upper Cayuga	M	H	M	L	H	L
Lower Cayuga	L	H	H	M	L	H
Buttermilk Creek	L	M	L	L	L	L
Enfield Creek	M	H	M	L	L	L
West Branch Creek	L	M - H	M	L	L	L

Note: L= Low; M = Moderate; H= High

Numerous recommendations were presented in the foregoing chapters relative to future actions in the streams and watersheds under study. These are summarized below:

Summary of Recommendations for Six Mile Creek

- Increase Channel Roughness
- Stabilize Channel Bed Headcuts / Knick Points
- Create Incised / Supplemental Floodplains
- Minimize Rigid Retaining Walls
- Modify the Siltation Basin
- Protect the Gas Main Crossing
- Institute Floodplain Management Measures
- Monitor Tributary Gullies.

Summary of Recommendations for Fall Creek

- Address Eroding Tributaries
- Replace Undersized Bridges
- Remove Abandoned Railroad Bridges
- Consider Future Water Supply Sources
- Modify Flood Control Dam on Virgil Creek
- Preserve Vegetated Buffers along the Channel
- Institute Floodplain Management Measures
- Stabilize and Plant Roadside Ditches

Summary of Recommendations for Salmon Creek

- Address Bank Erosion Upstream of the Falls
- Remove the Log Jam in Lansing
- Search out and Stabilize Larger Headcuts
- Mitigate Upland Sources of Erosion

- Encourage Stormwater Management
- Preserve Vegetated Buffers along the Channel

Summary of Recommendations for Cayuga Inlet

- Further Evaluate Lateral Migration South of Routes 13 and 34 – Begin Monitoring
- Address Bank Erosion at Select Locations
- Evaluate Fish Passage at Grade Controls
- Further Evaluate Placement of "Anchor Points" along the Main Channel Stem
- Institute Floodplain Management Measures

Summary of General Recommendations

- Preserve Vegetated Buffers along Channels
- Conduct Flood Studies to Define Flood Zones
- Enable/Promote Public Access
- Capitalize on Educational Opportunities
- Require Sediment and Erosion Controls for Construction Projects
- Monitor – Turbidity, Erosion, Restoration

16.2 Management Practices, Program Operation and Coordination

The current Flood Hazard Mitigation Program funding is geared towards the protection of structures and facilities to minimize flood damages. However there is no stated goal or criteria in the funding guidelines that would place emphasis on or give priority to sustainable restoration alternatives, watershed approaches, or restoration projects that would prevent damage to the natural environment, as opposed to existing structures or property. Additionally, the current program does not account for a hierarchy of priorities that are consistent with a regional watershed approach.

The County is to be commended for its foresight in suspending its funding program pending a comprehensive watershed needs assessment. The current funding mechanism is a good one and the existing framework serves as an excellent starting point from which to develop a watershed-based approach. It is recommended that the County's current funding application and supporting guidelines be modified to incorporate a priority ranking system by which future projects can be evaluated. A ranking system can be numerical, weighted numerical, or simply utilize a "high" "moderate" "low" system to assign priority among competing projects. A suggested set of criteria elements is provided below:

- Location of the project within one of the identified priority stream segments;
- Use of natural stabilization techniques over spot treatments;
- Consistency with a watershed approach;
- Potential for ill-effects of upstream and downstream reaches;
- Level of technical analysis and design documentation provided;
- Future maintenance requirements;
- Ability to provide hydrologic benefits through detention or infiltration of runoff;
- Ability to provide water quality renovation;
- Consistency of the proposal with establishment of a riparian corridor; and
- Impact on biological integrity of the stream.

Minimum requirements of eligibility should also be developed for application to project review and funding award, as well as criteria for rejection of proposals. This would include inconsistency with the stated watershed goals or local regulations, lack of technical documentation, or inadequate study or documentation.

In the past, the total annual funding under the Flood Hazard Mitigation Program has been limited to $25,000 per year, with a requirement of equal matches from the project proponent and the municipality wherein the project would occur. This equates to a maximum potential annual pool of $75,000. A mechanism that would enable funding of multi-year projects of larger magnitude would be desirable. Additionally, the program would benefit from having the flexibility to roll unused funding from one year into the next, in the event that the number and/or scope of eligible projects is not sufficient to expend the available funding in a given year.

Consistent with the recommendations contained in this assessment, additional coordination among the host municipalities within a single watershed would be beneficial to a more holistic restoration approach. The role of the Tompkins County Planning Department as a central hub for planning activities among the municipal governments is both appropriate and desirable.

16.3 Funding Considerations

The County is encouraged to monitor funding trends at the state and federal levels. Since September 11, 2001, the focus of federal funding has shifted to homeland security and is not heavily weighted towards stream restoration or flood hazard mitigation. Some possible sources of funding may include the National Oceanic and Atmospheric Administration (NOAA), the Environmental Protection Agency (EPA), and the State of New York Department of Environmental Conservation (DEC).

16.4 Implementation and Future Needs

The site-specific recommendations described herein include excellent short-term implementation candidates that should be pursued as funding allows. The programmatic recommendations should be initiated as soon as practical. However, given the depth of coordination that will be required among the member municipalities, along with the complexities of the public process to implement any regulatory changes, complete implementation will likely take several years.

The County can begin to work towards the long-term goals and objectives of a holistic watershed approach by initiating changes to its current funding program. Many of the long-term watershed measures presented in the overall recommendations described above, will require funding that significantly exceeds the annual allocation of $25,000 or the combined contribution of $75,000 per year with "matching" funds.

This Needs Assessment has been conducted on a "macro-scale" level. While the assessment has enabled development of a broad scale management strategy, establishment of a hierarchy of specific projects with cost estimates and implementation schedules will require more in-depth investigations of the moderate and high priority issues and stream reaches.

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MERGING RIVER MECHANICS AND FLUVIAL MORPHOLOGY FOR RIVER MANAGEMENT

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Abstract

The sciences of classical hydraulic engineering and fluvial morphology have evolved along separate and sometimes divergent paths. The former is based on empirical, laboratory, and theoretical data while the latter emphasizes field observations and measurements of natural systems. However, neither system provides a complete and independent understanding of stream stability and sediment behavior. This paper explores how they compliment rather than compete with each other.

Introduction

The planning, design, and construction of river rehabilitation and restoration projects is still an evolving discipline that blends art and science. It is increasingly an interdisciplinary process involving hydrology, hydraulics, ecology, geomorphology, water quality, and landscape design plus social and cultural considerations. Regulatory programs, public concerns, and the adverse impacts of historic engineering projects have increased interest in alternate planning and design goals and procedures. Several distinct approaches have been developed to evaluate rivers and are often viewed by designers as competing methodologies such as fluid mechanics versus fluvial morphology. Each design philosophy has strengths and weaknesses which lend them to specific applications. The purpose of this paper is to identify key characteristics of each design approach and presents guidelines on how to select and merge appropriate technologies. The procedure has been in use for many years (MacBroom, 1981) and is updated to reflect scientific advances. Specific project types include natural-like flood control, habitat restoration, fish bypass channels, and dam removal.

Miller and Skidmore (2001) provide an excellent introduction to what are described as analog, empirical, and analytical techniques of evaluating river channels and designing restoration projects that stimulate natural systems. The analog approach of fluvial geomorphology is based on observation and classification of historic "stable" rivers assuming equilibrium conditions and using them as a guide for nearby restoration projects, while the empirical approach use quantitative observations to establish basic relationships of channel geometry. Analytical design approaches use theoretical quantitative techniques to compute channel hydraulic flow characteristics, stability, and sediment transport. The analytical approach attempts to describe and forecast river processes based on physical laws including conservation of mass, energy, and momentum plus empirical theories.

Channel Stability

One of the foundations of river restoration literature is the goal of creating stable channels that are in long-term equilibrium (Rosgen, 1998; Burns, 1998). Burns describes stability to mean that the channel does not change significantly in profile, cross section or planform characteristics over the long-term, nor that the channel is fixed in place." Others have defined stability as a long-term equilibrium condition where short-term changes tend to vary about a mean. A third stability concept is based on sediment transport continuity where the mass inflow to a reach equals the mass outflow with no net scour or deposition. Another basic tenant of river restoration is a desire to return degraded ecosystems to a close approximation of its remaining natural potential (USEPA, 2000).

A fundamental conflict arises when the nature state of a stream is instability due to active aggradation, incision, and changes in planform. Instability is more common in headwater source areas and lowland depositional areas and may be caused by either natural or unnatural causes on short or long-term scales. Short-term events creating long-term instability include great floods, land slides, forest fires, earthquakes, water diversions, and urbanization; long term events include base level or sea level elevation changes, climate change, and tectonic upland. Many stream restoration efforts occur in urban areas where human activities have altered watershed hydrology and streams have been piped, channelized, filled, or disconnected from floodplains and wetlands. Such streams are not likely to return to natural conditions; alternate goals need to be established.

Channel restoration designers are confronted with a broad range of planning and design techniques, most of which are only valid for specific types of channels or particular geologic settings. The available techniques also very widely in their level of effort and the type of data necessary to utilize them. Channel classification systems can be used to aid in the selection and application of design procedures. Numerous channel classification systems have been developed to help categorize and group channels by characteristic metrics such as morphological patterns, valley form, substrate, biological systems, and channel forming processes. Classification systems provide a useful communication tool, each with consistent definitions and some classification systems have been integrated into channel design procedures. However, they can over simplify complex systems (Doyle 1999) and tend to ignore geomorphic convergence when different processes lead to similar physical forms (Miller 2001). Most classification systems focus on natural undisturbed rivers in contrast to restoration project which often involved unstable rivers or previously channelized rivers.

There are numerous channel stability classification systems and models available. However, they tend to focus on natural channels and only the threshold and active alluvial bed categories. In actual practice, we also find many rigid boundary channels with fixed perimeters, plus depositional channels that are not in equilibrium. It has also been found that many river restoration projects involve unnatural channels that have been previously disturbed and do not fit into existing classification systems. A stability classification system is show in Figure 1.

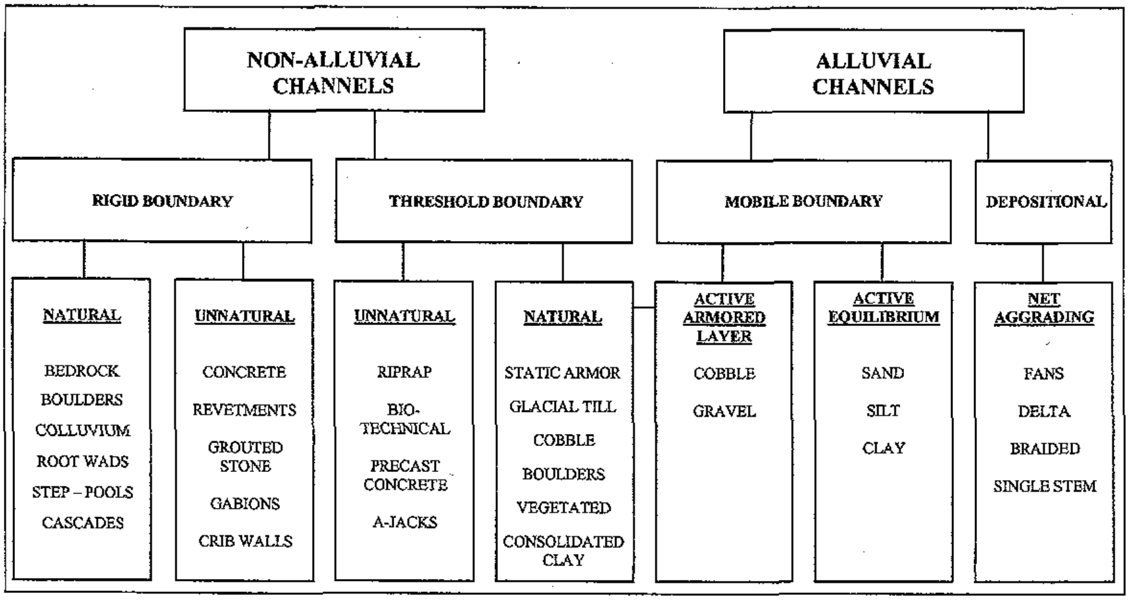

Figure 1. Stability Classification

Non-Alluvial Channels

Non-alluvial channels have semi-permanent fixed boundaries that are insensitive to normal flow rates. They will generally have sediment transport rates that exceed sediment sources and yields, hence there is limited sediment storage along the channel and little floodplain formation. They are more prone to scour than deposition. The first subcategory is fixed boundary channels whose beds and/or bank positions are naturally controlled by frequent to continuous rock exposures. They are common in mountainous and upland areas and reflect areas where channel erosion, however slow, exceeds sediment deposition. Bedrock channels on sedimentary rock with horizontal bedding planes tend to have wide flow widths compared to their flow depth, while bedrock channels on erosive rock or following faults may tend to be narrow and deep. Another example of fixed boundary channels are those that have been modified with rigid linings of concrete, sheeting, gabions, stone, or articulated mattresses for flood control projects, canals, or erosion controls.

A second type of non-alluvial channel is dominated by non-bedrock perimeter materials that seldom (if ever) are subject to motion due to stream flow and lack general sediment deposition. The channel perimeter acts as a rigid boundary during most flow conditions but initiation of motion and scour occur when threshold velocities or shear stresses are exceeded during rare flood events. Natural examples of threshold channels include those armored with cobbles, channels in glacial till, and those controlled by colluvial deposits from hillslope or landslide processes. In the northern climates, many threshold channels are located in underfit glacial meltwater valleys where they have insufficient capacity or competency to transport ancient course sediments. In humid climates, channels with dense vegetation that stabilizes the banks and resists erosion may act as a threshold channel. Many manmade channels with artificial linings often behave as threshold channels. Semi rigid linings such as stone riprap, precast concrete units, and bioengineering measures remain stable until substantial velocities or shear are reached, then become unstable. A common design procedure is to design linings to be stable for specified flow criteria and to treat them as a rigid boundary up to that threshold.

The threshold conditions may be exceeded during periods of high velocity and shear stress that initiate motion of some or most particles, thereby acting temporarily as a mobile bed channel.

Alluvial Channels

The mean widths, depths, and profile slopes of mobile boundary alluvial channels form in proportion to their flow slope and sediment load at a channel forming discharge. The latter is often identified with respect to flood frequencies (one to three year) or bankfull flow conditions. The width has also been shown to be a function of bank vegetation and erosion resistance. The channel stability and dimensions are sensitive changes in flood flow rates and sediment loads and tend to reflect the watershed's recent flow regime. Equilibrium channels with coarse sediment or high sediment loads will tend to be wider and shallower than ones with fine material or small sediment loads. The behavior of gravel bed streams can be particularly difficult to predict. Some have active mobile beds with bedload transport, others are armored and stable.

Design Flows

The bankfull width and depth provide only one pair of cross section dimensions. Designers are also very concerned about the ecological value of the inner channel that carries low flows during critical life stages of key species such as spring migratory periods for anadromous fish and spawning periods for other animals. Restoration projects must identify their essential flow regimes for ecological purposes and determine appropriate flow rates and cross section shapes. For rivers with regulated flow regimes, channel restoration design should address flow management strategies (Postel and Richter, 2003). Floodplains and the rare floods that create them are also essential parts of the fluvial cycle often neglected in traditional geomorphic based channel restoration that focuses on bankfull discharges. Designers should not ignore that many floodplains are developed and that provisions are needed for larger than bankfull discharges and that banks often need to be stabilized against large floods to protect water quality, reservoirs, private property, and infrastructure.

Typical Restoration Design Flows

Minimum mean monthly discharge
Key discharges during aquatic species life stages
Migratory season flow rates
Channel Forming discharges
10-, 50-, 100-year frequency flood flow rates
Future flow rate predictions for modified watersheds

Fluvial Morphology Based Design Methods

The empirical approaches to fluvial geomorphology use a broad data base of field observations to create plots of width, depth, channel cross sectional area as a function of watershed area or discharge. Early examples of the empirical canal design approach are the regime equations developed in India and Pakistan, beginning in the late 1800s. They evolved into the Lacy and Blench (1969) canal equations, and were later modified to approximate alluvial rivers (Simons and Albertson, 1963). It was shown that the coefficients in the simple power equations were highly dependent on substrate and sediment type. The U.S. Army Corps of Engineers included the modified Lacy regime equations in their Channel Stability Manual (printed by ASCE, 1997).

Empirical hydraulic geometry relationships for channel bankfull width and depth are based upon open channels with variable discharges, unlike the regime equations for steady flow in canals. Leopold and Maddock (1953) presented data in a format similar to the earlier regime equations and many researchers have continued this style.

An ASCE Task Committee Paper (1982) presents a detailed comparison between regime and hydraulic geometry equations and summarizes the early literature acknowledging data scatter and variable coefficients. Three main approaches to improving use of basic hydraulic geometry equations were described, including: use of physical classification systems, use of sediment transport relations and flow hydraulics, and use of an additional erosion and equilibrium equation.

It has become common practice to stratify hydraulic geometry data by stream type, geographic regions or both to try to improve accuracy. Several state and federal agencies have adopted channel design procedures based on reference reaches, as described by Rosgen (1998). The popular Rosgen (1994) classification system aids in the development and selection of regional curves that correspond to specific stream channel types rather than to larger groups of all streams. The technique helps to select stream and valley types that will be used as a model for the restoration site. Reference reaches are used to develop regime type hydraulic geometry equations that are for specific stream classifications in a region, hopefully improving the accuracy of regime equations. Reference reach techniques can be useful in stable watersheds when similar stream types are available for analog models. However, they are prone to both scale and temporal factors that limit their use.

Use of the watershed area as the primary geomorphic function should be discouraged due to the wide variation in discharges for a given watershed size. For example, discharges (and channel geometry) are known to vary with the shape and slope of a watershed, soils and geologic formations, vegetation, surface water storage in lakes or wetlands, and degree of urbanization. Using a flow function such as the bankfull or specified flow frequency eliminates many of the watershed variables.

A weakness of both analog (reference reach) and empirical (hydraulic geometry) approaches is assumed stable equilibrium conditions that reflect a channel's recent past performance rather than long-term physical processes. Dynamic watersheds with modified land uses and/or runoff rates pose a special problem. Activities such as timber removal, agriculture, surface mining, and urbanization can alter watershed hydrology and their channels may not have had time to reach a new equilibrium. Furthermore, restoration of their channels should consider future flow rates and not just historic conditions. Channels in modified watersheds are likely to be subject to higher peak flows due to loss of vegetative cover, increased impervious area, filling of wetlands and floodplains, and channelization. These watershed processes may increase peak flows, diminish base flows and increase sediment yield, resulting in channel incision and widening plus downstream deposition. Hydrologic modifications in a watershed may also include dams that alter flow rates and trap sediment, dikes that limit overbank floodplain flow, lined channels that are unable to adjust to new flow regimes, and culverts, bridges or utilities that alter flow patterns (Schwortz et al, 2003).

Burns (1998) discusses the limitations of hydraulic geometry equations and points out that they do not explicitly consider sediment transport and are applicable mainly to channels with low bed material loads. However, empirical geomorphic observations do provide important information on predicting river patterns, meander geometry, and on micro-features such as pools and riffles.

River Mechanics Design Methods

The analytical river mechanics approach to channel evaluation and design used for most of the 20th century is based on flow and resistance equations to predict water depths and velocities. Historically this resulted in the design and construction of large trapezoidal channels that were sized to convey a specified peak flood flow, but created adverse environmental and community impacts. There are multiple combinations of channel width, depth, and slope that can theoretically convey a given discharge rate but some combinations will be subject to scour or deposition, resulting in the common use of rigid or threshold boundary linings. The bed and bank stability can be quantified based upon threshold velocities or shear stress (Lane, 1955; Fischenick, 2001). While hydraulic theory has proven to be successful in predicting flow depths and velocities in rigid boundary channels, it is unable to reliably predict the optimum combination of channel dimensions for sediment transport equilibrium and ecologically sound conditions. Nor do hydraulic equations address channel patterns or profile form.

Sediment Transport

Analytical techniques are increasingly useful when supplemented with basic or advanced evaluation of sediment transport. The procedure requires an initial hydraulic analysis of flow velocity and/or shear stress and uses the result to estimate suspended, bed material, or total transport. This provides another set of equations to assess whether the selected channel dimensions and shape can convey the specified water flow and sediment load. Since actual measured sediment loads are seldom available, one approach is to compute the transport capacity in a nearby stable channel reach and then provide similar capacity at each cross section in the design reach, adjusted for changes in discharge rate.

The evaluation of a channel's sediment transport capacity is linked to its hydraulic flow characteristics of depth, width, slope, velocity, and shear stress. In addition, information is necessary on the size distribution of granular sediment particles and properties of cohesive materials. Basic computations may be performed for uniform steady flow and proceed more comprehensive analysis of nonuniform or unsteady flow. The results must be carefully reviewed and used as the sediment transport phenomena is not fully understood or defined.

Uniform steady flow is the simplest scenario and can be used to compute transport capacity at each individual cross section plus a stable comparative reach. Channel cross section widths, depths or slopes are iteratively adjusted to achieve the desired flow and sediment capacity. Transport values at complex, high risk, or high value projects should use nonuniform hydraulics and multiple flow rates. An iterative loop for advanced analysis may be performed with computer models that adjust width, slope, or roughness.

Computer models are increasingly able to integrate the analysis of hydraulic flow and sediment transport, using interactive loops to adjust the channel dimensions to obtain sediment equilibrium conditions. Some of the limitations to full channel modeling include the armoring of the bed, the effect of bank vegetation, variable substrate layers, cohesive soils, and biochemical processes, determining initial and optimum channel widths, meander patterns, and profile features such as pools and riffles (ASCE Task Committee, 1998).

Design Aids and Procedures

The actual planning and design of open channels and stream restoration projects is often performed by non-specialists who rely on various manuals of practice produced by local and state agencies, professional societies, and in text books. As in many fields, the manuals of practice often lag 5 or 10 years behind the related academic or agency research papers and tend to reformat and merge the appropriate research into a sequential series of steps used by designers. However, the wide variety of channel types and site specific conditions defy use of simple solutions.

Many of the traditional design guides concentrate on channels with rigid boundaries that will be lined and are rigid at the specified design flow. Representative publications include "Design Charts for Open Channel Flow" (Federal Highway Administration, 1973), "Design of Open Channels" (Soil Conservation Service, 1977), Hydraulic Design of Flood Control Channels (Corps of Engineers, in ASCE 1995), and "Design of Channels with Flexible Linings" (Federal Highway Administration, 1988). The contemporary public domain computer programs for open channels such as HEC-2, WSP-2, and HEC-RAS are also based on rigid boundaries.

Several recent publications help consolidate decades of research on alluvial channels and sediment transport with an emphasis on design applications. Copeland et al (2001) addresses several methods of alluvial channel design including reference reaches, hydraulic geometry relations, stability assessment, and sediment transport assessments. Soare and Thorne (2001) present data on sand and gravel bed meandering rivers that aid in the design process. In addition to hydraulic channel geometry, there is extensive information on meander geometry, location and size of meander bends, and analytical techniques. Highways in the River Environment (Federal Highway Administration, 2001) is an important guide for the transportation sector and addresses both rigid and mobile boundary channels.

Figure 2 depicts the type of information that is available from scientific sources or methodologies. It is noted that none of the available design techniques provides all the information of interest. For example, the geomorphic design techniques do not provide computed flood water or low flow water profiles, nor sufficient information to determine the size of floodways or floodplains for rare events. The traditional rigid boundary hydraulic analysis does develop data on water profiles, velocity, and threshold stability but does not address optimum channel widths and depths, nor planform geometry.

			MAIN CHANNEL									
DESIGN METHOD	FIXED BOUNDARY CHANNEL	ALLUVIAL CHANNEL	AREA	OPTIMUM WIDTH DEPTH	VELOCITY	WATER PROFILE	FLOOD PLAIN FLOW	RIVER PATTERN	STABLE SLOPE	BED STABILITY	FULL HYDROLOGY RANGE	SEDIMENT TRANSPORT RATES
REGIME METHOD		X	X	X	±				X	X		
REGIONAL HYDRAULIC GEOMETRY CURVES		X	X	X				X				
REFERENCE REACHES		X	X	X	X			X	X			
HYDRAULIC THEORY	X		X		X	X	X		X	X	X	
BASIC SEDIMENT TRANSPORT	X	X	X	X	X					X	X	X
ADVANCED HYDRAULIC AND SEDIMENT TRANSPORT	X	X	X	X	X	X	X	±	X	X	X	X

Figure 2. Design Methods and Data Obtained

It is apparent that a comprehensive restoration design may require a combination of geomorphic and theoretical engineering methodologies. Figure 3 provides a generalized model with a sequential series of steps to assess and design restoration projects. Many projects in mountainous or upland areas, and previously channelized rivers, have either rigid or threshold boundaries and can be analyzed with a moderate level of effort. If they are found to be unstable or have low threshold levels, then one can either allow erosion, provide an erosion resistant lining, or perform an alluvial channel analysis. In contrast, design of restoration projects with mobile boundaries requires the additional analysis of channel width and depth. Hydraulic geometry design

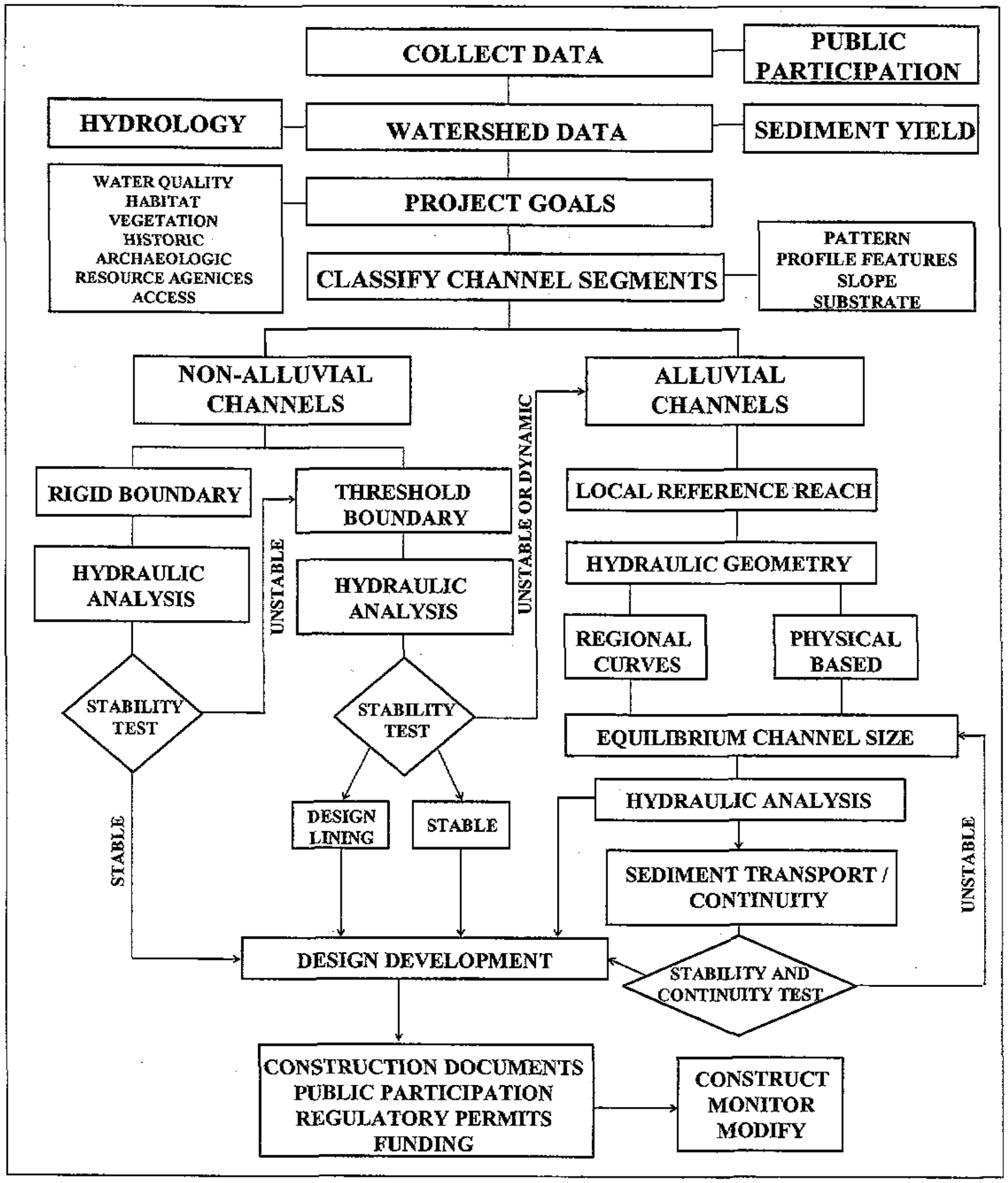

Figure 3. Stream Restoration and Channel Stability Design

methods may be adequate for simple low risk situations, while sediment transport assessments are required for complex sites. In the latter case, regime or hydraulic geometry equations for channel width, depth, and slope may be used as a first trial for subsequent sediment transport analysis.

The USCOE HEC-RAS River Analysis computer model has been updated with inclusion of routines to analyze and design stable channel cross sections with mobile beds. The three available methods are Copeland's technique from the Sediment Analysis Model (SAM), Blench's version of the regime equations for silt or fine sand, and tractive force.

Summary

The merger of geomorphic and river mechanics provides a broad range of technologies for the design of open channels that simulate natural systems.

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